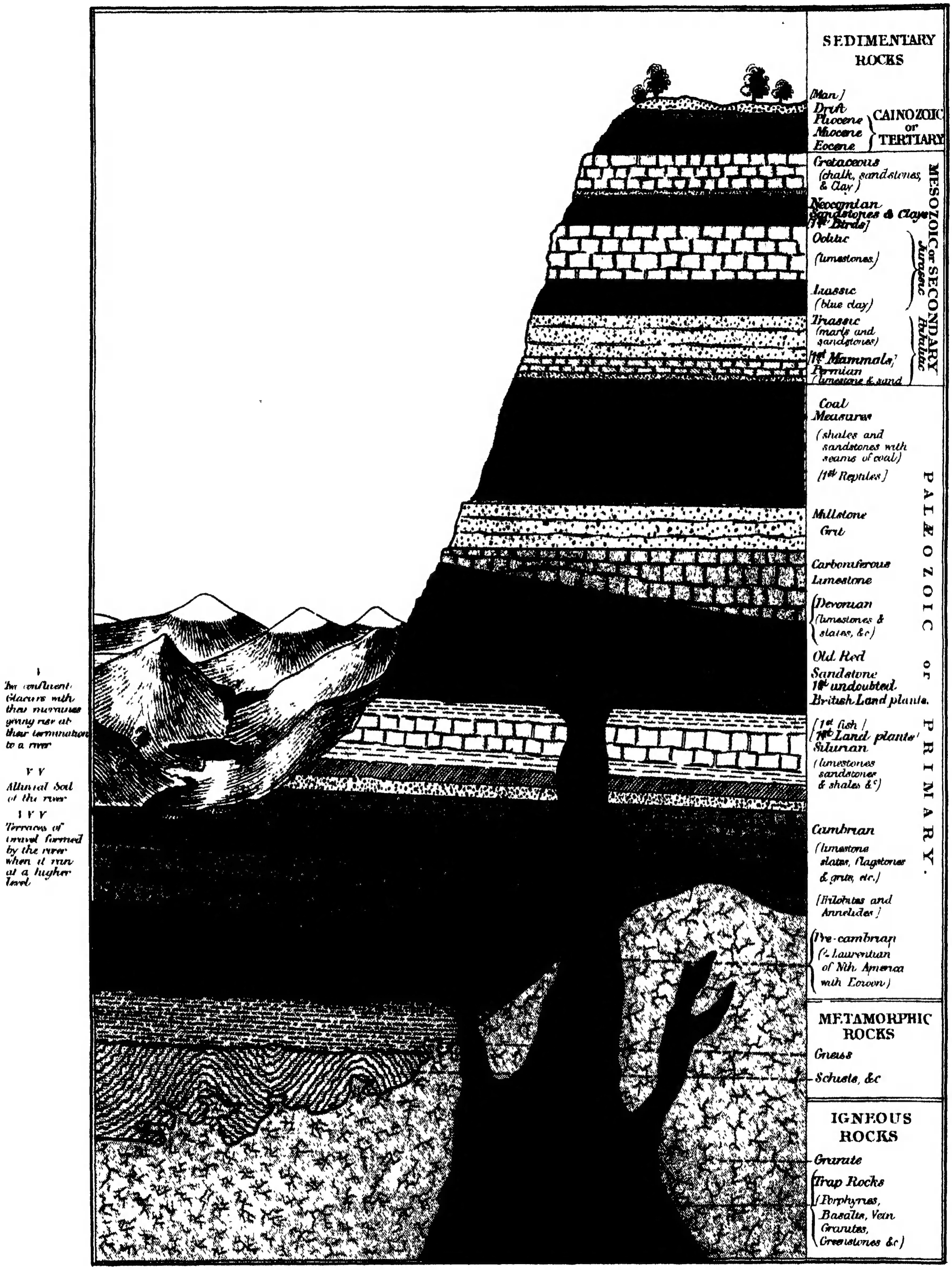


A DIAGRAMATIC SECTION SHOWING THE ORDER OF SUCCESSION OF THE VARIOUS ROCKS THAT COMPOSE THE CRUST OF THE EARTH WITH MORE ESPECIAL REFERENCE TO THOSE FOUND IN ENGLAND.

# SCIENCE FOR ALL

EDITED BY

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# INTRODUCTION.

IT is the recorded opinion of Samuel Johnson that "he who enlarges his curiosity after the works of Nature demonstrably multiplies the inlets to his happiness." This dictum is one which admits of no gainsay. The trouble has been always to enable him to do so. The world lies all around, full of wonders, full of mysteries, full of miracles, but the guides are few, and the language in which they play the *cicerone* is often unintelligible to those whose previous life has had to deal with facts and things that needed none of their vocabulary. Books there are in abundance—good, bad, and indifferent, and all full of knowledge about the very things which the student wishes to learn. But the books also pre-suppose previous knowledge, and, moreover, they teach too much. One lifetime is not sufficient to read half of them, and the time those who have not devoted their days and nights to science can allot to even one branch is insufficient to master its literature. Persons of every class, every rank, and every age desire to learn something about the daily sights and sounds that they see and hear around them. But they too often find that the pathway to knowledge is closed by the technicalities that the text-book writers have thrown in their way, or that in the search for what they daily see, and desire to have explained, they are compelled to wade through a weary flood of what they may never see, and therefore cannot be expected to desire to have explained. In SCIENCE FOR ALL we propose to provide food for such readers—food for the mind that feels an interest in every-day SCIENCE, and science that can be understood by ALL.

We shall pluck the leaves from the hedge-rows, or pick them up from under the trees, and then and there read a lesson to the reader We shall break the chalk from the sea cliff and the limestone from the quarry, or with the coal in the fire as our text, try, with the aid of those whose life has been devoted to sifting the grain from the chaff, to explain what these teach us. We shall not suppose that the reader knows anything of science, and therefore will adopt the same method in explaining what is seen as the reader would do if he or she tried to find out all about it unaided. We shall lead our pupils on from the known to the less known, from facts which are familiar and patent to those which are less familiar and more abstruse. We shall show him the method of scientific reasoning by first pointing out the facts, and then asking him to agree with or differ from us as to our interpretation of the information we have collected together. In other words, we shall adopt the natural method, taking our facts as we find them in Nature, and reasoning from them, not commencing with theories, and then finding facts to support these foregone conclusions, which must first be taken for granted. Science is ever advancing, and our work will be abreast of the latest discoveries and views, though at the same time it will be our duty to avoid mere speculation, and cling to the sure ground of ascertained fact. By doing so we run no likelihood of exhausting the mine. It is only half worked, and the treasures of truth to be extracted are endless. The sky is full of them, the air is filled with them, the earth teems with them ; the plants, the animals that feed on them, our own bodies and their bodies, the sea and the lake, the river and the swamp—the whole world supplies materials.

In SCIENCE FOR ALL it will not be the mere curiosities of science which will be explained. Each paper will be complete in itself, so far as it goes, and each will contain the explanation of some principle in

the science of which it treats, the object discussed being, as it were, the peg on which the remarks are hung. Thus "Water, Ice, and Steam" opens up some of the most important fields in physics; "A Fallen Leaf," properly examined and understood, is the key to the whole science of plant life. The person who can say that he understands the nature of a lump of coal is on the highway to know the broad principles of geological science; and the study of a crab and its changes is a subject of infinite importance. "The Man in the Moon" has been a familiar personage for ages, but if his back and his bundle are studied, there open out before us other worlds which we can never reach save with the eye. How does a star twinkle? What is "the stuff dreams are made of?" Where came all the rocks scattered over highland hills—whence came the rocks and shells in the clays alongside the lochs, and what grooved these rocks as if a file passed over them? Why are we hungry, and why are we sleepy? What is a whirlpool—how does water circle round in one place, and rise in the air in a waterspout in another? How does a fish swim and a bird fly? How does a pine tree grow in Britain and a palm tree in Bermuda? Why do the swallows fly south in winter, and what takes the knot to lands beyond Greenland in summer? What is the chemistry of a brewer's vat, and of a gas jet? How have the lakes been made, and how do the Alpine ice rivers descend? What sends the message along the telegraph wire, destroys man and beast by lightning, and lights up the darkness with a candle such as human skill has never made? These and a hundred other questions we are daily asking ourselves, and these queries it will be the duty of the writers in this work to explain. Thus the reader may master the mystery of common things, and in time learn all that is necessary for him to ascertain regarding the daily work of Nature around him.

Technicalities merely as such we shall not trouble ourselves with. It will be our interest more to learn about the things themselves than to ascertain the names—useful or not—which the nomenclators have affixed to them. If the reader can understand what he sees, how it is done, what is done, how the machine of nature in a leaf or a plant, in a grain of dust or a coal-field works, then we shall be content. "J'ai toujours cru qu'on pourrait être un très grand Botaniste sans connaître une seule plante par son nom," writes Jean-Jacques Rousseau, a man of science of no mean accomplishments. And if one can be a "very great botanist without knowing the name of a single plant," so might he be a zoologist, a geologist, or a physicist, if not great, at least intelligent, without meantime troubling himself with the technicalities of that portion of science which he learns in our familiar lessons. Was it not Schiller who said of science that

"To some she is the goddess great,
To some the milch-cow of the field;
Their only care to calculate
How much butter she will yield?"

Our endeavour will be to show the reader what wonders he hourly passes by, and that in his daily life there are endless shows he has not seen. "Nature," as Goethe says, "will be reported. All things are engaged in writing their own history. The planet and the pebble go attended by their shadows; the rolling rock leaves its scratches on the mountain; the river its channel in the soil; the animal its bones in the stratum; the fern leaf its modest epitaph in the coal; the falling drop makes its sculpture in the sand or stone. Not a foot slips on the snow or along the ground, but prints, in characters more or less lasting, a map of its march. The air is full of sounds, the sky of tokens, the ground of all memoranda and signatures: subjects covered with hints which speak to the intelligent."

# SCIENCE FOR ALL.

## THE MAN IN THE MOON.

By the late Richard A. Proctor.

THE irregular markings on the face of the moon attracted attention long before the invention of the telescope, and seem from very early times to have been regarded as forming the features of an imaginary face. We find several references to this imagined face in writers of antiquity. In some cases the features recognised were those of a man, in others of a woman. The "man in the moon" of later days seems to have been usually pictured as a man bearing a large bundle of sticks on his shoulders, and accompanied by a dog. But those who have not heard of the sticks and dog, generally imagine a face, only, in the full moon. If the picture of the moon shown in Fig. 2 is held at a considerable distance from the eye, the general appearance presented by the full moon is shown. Then the dark parts O and G are the eyes of the full-faced man in the moon, the eyebrows sloping downwards and rather heavily marked; the mouth occupies the lower part of the dark marking S and T; and the other features fall correspondingly. The full figure of a man with his bundle of sticks and little dog is, I believe, formed thus:—H is his head, O and G the parts of the bundle on either side of his shoulders, his legs lie on the dark marking S, and T is the little dog. But I am by no means sure how the figure should be formed, neither is the point one of any importance.

It is, however, important to notice that from the very earliest times men have recognised always the same features in the full moon. They have also found that, as the moon waxes and wanes, the same features are still seen as far as the illumination extends. In other words, men have known from time immemorial that the moon in her circuit around the earth turns always the same face towards us. This is in reality one of the most remarkable circumstances known about the moon, though its significance has been recognised only in recent times.

The study of the moon's disc with the naked eye did not reveal any facts of interest respecting the moon's physical condition, though carried on for thousands of years, and by some among the chief astronomers of antiquity. The views held by Anaxagoras 500 years before Christ were in the main the same as those held by Copernicus, and by Galileo himself until the eventful year 1609, when he first turned a telescope upon the moon. It was supposed that the markings indicate the presence of lands and seas, valleys and mountains on the moon, that she is a globe in many respects like our earth, and may probably be, like her, the abode of life.

But even before the invention of the telescope many important facts were discovered respecting the moon's motions. Such researches, carried on successfully from the time of Hipparchus to that of Galileo, were continued thereafter, becoming more and more exact as instrumental appliances were improved, and culminating in our present very exact knowledge of the moon's distance, size, motions, and perturbations. In an account, therefore, of the moon, as known from phenomena, the consideration of these points naturally precedes that of her physical condition.

The earliest observers noted that when the moon is opposite the sun, she shines with a full disc; that when near him in the sky she shows only a fine crescent of light, with the horns turned from the sun; and that her disc gradually fills as she recedes from the sun's place in the heavens, and gradually becomes less and less fully illuminated as she approaches him. They could thence readily infer that she must be a globe illuminated by the sun, and very much nearer to the earth than the sun is,

There is no simpler or better proof of this relation than the following. Let S, Fig. 1, be a lamp lighting a room not otherwise illuminated; M a small white globe attached to a bent wire, M E H, held in the hand, H, of the observer. Now let the wire be slowly twirled, the part E H remaining upright, so that the ball M moves round through the positions 1, 2, 3, 4, &c., to 8. Then if the observer so move his head as to look at the ball M always along the arm E M (or as nearly in that direction as he can, for when M is near 5 his head will be in the way of the rays from the lamp if he looks exactly along

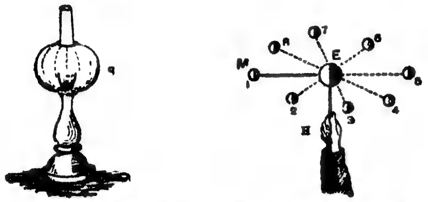

Fig. 1.—Diagram to illustrate the Phases of the Moon.

the arm E M), he will see the ball passing through all the phases of the moon—dark at 1, a crescent of light at 2, one-half bright at 3, three-quarters bright at 4, all bright at 5, three-quarters bright at 6, one-half bright at 7, a crescent of light at 8, and dark again at 1. Since he looks always in the same direction as a small observer placed at E would look, it is clear that an observer at the centre of the circuit of the small globe M, would see that globe passing through all such phases as the moon passes through. It follows that the moon's phases are explained by supposing her a globe as M, circling round the place E, corresponding to the home of the terrestrial observer, and illuminated by a more distant light S, corresponding to the sun. It is also easily seen that no other explanation is available. Hence we learn that the moon is an opaque globe circling round the earth; that she is illuminated by the sun; that she is much nearer than the sun; and therefore, since she looks no larger, that she is a much smaller globe.

We must next briefly consider how, by watching the moon, the early observers ascertained the general laws of her motion. In so doing we are, in fact, going back to the very beginning of astronomy; for there can be little doubt that the moon's motions were studied and timed long before the apparent motions of the sun, planets, and stars were examined or even noticed. The passage of the moon through the four quarters of her seeming circuit—that is, from invisibility to half full, from half full to full, from full to half full, and from half full to invisibility—gave the week as a measure of time, though men must soon have noticed that the lunar month does not contain exactly four weeks. Probably at first the time when the moon is invisible was regarded as marking a separation between successive months, and the rest of the month was divided into four quarters, each a week long, a usage of which traces remain in the Jewish festival and day of rest of the "new moon." Later the regular succession of weeks came in, the length of the lunar month being more exactly determined. It was found to be 29 days, 12 hours, $43\frac{1}{5}$ minutes. This is the *lunation*, sometimes called the *synodical month.*

Tracking the moon's course round the heavens, men found that it lies along a certain zone about $10\frac{1}{3}$ degrees wide, the central line of which is the sun's track (though this was only noted later). Most of the first observers seem to have divided this zone into 28 equal parts, called lunar mansions, each corresponding very nearly with the moon's motion among the stars during a single day. Closer observation showed, however, that she really completes the circuit of the stellar heavens in 27 days, 7 hours, $43\frac{2}{5}$ minutes. This is the *sidereal month.* It is easy to see why it is shorter than the common lunar month. To complete a common month the moon has to go round the heavens from the sun to the sun again, and the sun is all the time advancing slowly in the same direction. The sun takes one year to go once round the heavens, so that in a lunar month of $29\frac{1}{2}$ days he completes rather less than a twelfth part of a circuit; thus in a common lunar month the moon goes once round the stellar heavens and rather less than one-twelfth of a circuit *more.* The common lunar month, then, exceeds the sidereal month (in which she completes one circuit of the stellar heavens) nearly as one and a twelfth exceeds one.

In making these observations, the first astronomers could not fail to note the occurrence of eclipses, both of the sun and moon. Nor could they fail to understand the cause of eclipses. The explanation of the phases, as illustrated in Fig. 1, shows also why eclipses occur; for when the globe M is as at 1 it is seen by an eye looking along the rod E M as a black disc on the face of the lamp S, just as the moon is seen as a black disc hiding more or less of the sun's face in a solar eclipse. On the other hand, when the globe is as at 5, and the observer looks directly along the rod E M, his head comes between the lamp S and the globe M, throwing a shadow upon it, just as, during

an eclipse of the moon, occurring always when she is full, the shadow of the earth is thrown upon her. The details of the circumstances, however, on which the occurrence of eclipses depend must be examined hereafter in a paper specially devoted to the subject.

So also the measurement of the moon's distance, and therefore of her size, the determination of her mass or quantity of matter, and the history of the inquiries by which from her motions the law of gravitation was established, must be separately considered. Here we need state only the results to which such inquiries have led. It has been found, then, that the moon travels at a mean distance of 238,820 miles from the earth's centre, on a path nearly circular, but not quite, and also varying slightly from time to time in shape. The moon never, under any circumstances, approaches the earth within less than 221,590 miles, or recedes from her more than 252,950 miles. The breadth of the moon's face varies accordingly. When nearest to the earth (or in *perigee*, as it is termed), she has an apparent diameter of 33½′; when farthest (or in *apogee*), her apparent diameter is 29⅓′; her average apparent diameter is about 31′, or about 1′ less than the average apparent diameter of the sun. Her real diameter is about 2,160 miles, not much more than a fourth of the earth's; her surface 14,600,000 square miles, or between a thirteenth and a fourteenth of the earth's. The earth's volume exceeds the moon's nearly 49½ times. But the moon's material is either lighter or less compressed than the earth's, for the earth's mass exceeds hers, not 49½ times only, but nearly 81½ times. Her mean density, in fact, is almost exactly three-fifths of the earth's, and about 3½ times greater than the density of water—if the earth's weight has been rightly measured, a point which is open to some doubt.

Such is the globe on which those markings appear which have given rise to the conception of a "man in the moon." It is necessary to remember these dimensions in considering the markings, for otherwise we should form very imperfect ideas of their real nature. Noting that half the moon's apparent diameter is about 1,000 miles, we have a ready scale by which to estimate the dimensions of any lunar marking; only, of course, it must be remembered also that the face of the moon is not a flat circle, but one half of a globe, so that the parts near the edge are very much foreshortened. I have already stated that the moon turns always the same half towards us. Speaking generally, this is true; but it is necessary to explain that we can see rather more than half of the moon's surface. She turns on her axis once while circuiting once round the earth in the same direction. If *both* motions were uniform, and both in the same plane, she would turn always the same face exactly towards us. But whereas she turns uniformly on her axis, she travels round the earth with slightly varying speed. Thus her motion of revolution at one time gains, at another loses, on her motion of rotation, the effect of which is that at one time she appears as if rotated a little backwards, and at another as if rotated a little forwards, from her mean position; so that two fringes of her surface, one on the west and the other on the east of her medium face, are brought into view. This is called the *libration* (or swaying) *in longitude*. Again, her axis of rotation is not quite upright or at right angles to the plane in which she travels, so that we sometimes see a portion of her surface beyond her northern pole and a narrow northern fringe beyond her medium face, and at other times a narrow southern fringe. This is called the *libration* (or swaying) *in latitude*. In this way, and by viewing her from different parts of the large globe of the earth, we see about 58-hundredths of her surface instead of only 50-hundredths, as we should if there were no libration and the earth were very small.

It ought also to be noticed before we consider the condition of the moon's surface as shown by the telescope, that gravity at her surface is very much less than at the earth's. The quantity of matter which on earth we call one pound, would at the moon's surface tend downwards only with the same force as about 2 oz. 10½ drachms at the earth's surface; and a body let fall from a point not far above the moon's surface would in the first second fall through only 2 ft. 8 in. instead of 16 ft. 1 in., as happens with a body falling to the earth.

One of the first discoveries made (by Galileo) when the moon was examined with a telescope, was that the dark markings forming the features of the man in the moon are not seas, as had been supposed by Kepler and others, but portions of the solid surface of the moon, which, indeed, so far as can be judged, seems to be an entirely solid globe. Strangely enough, however, these dark regions, which are still called seas, correspond precisely with the regions which would be oceanic if there were water on the moon. They are great plains, lying at lower levels than the brighter parts. I say lower levels, for it has been shown by the German astronomers, Beer and Mädler, that these enormous plains are not all at the same level. Each also has its own

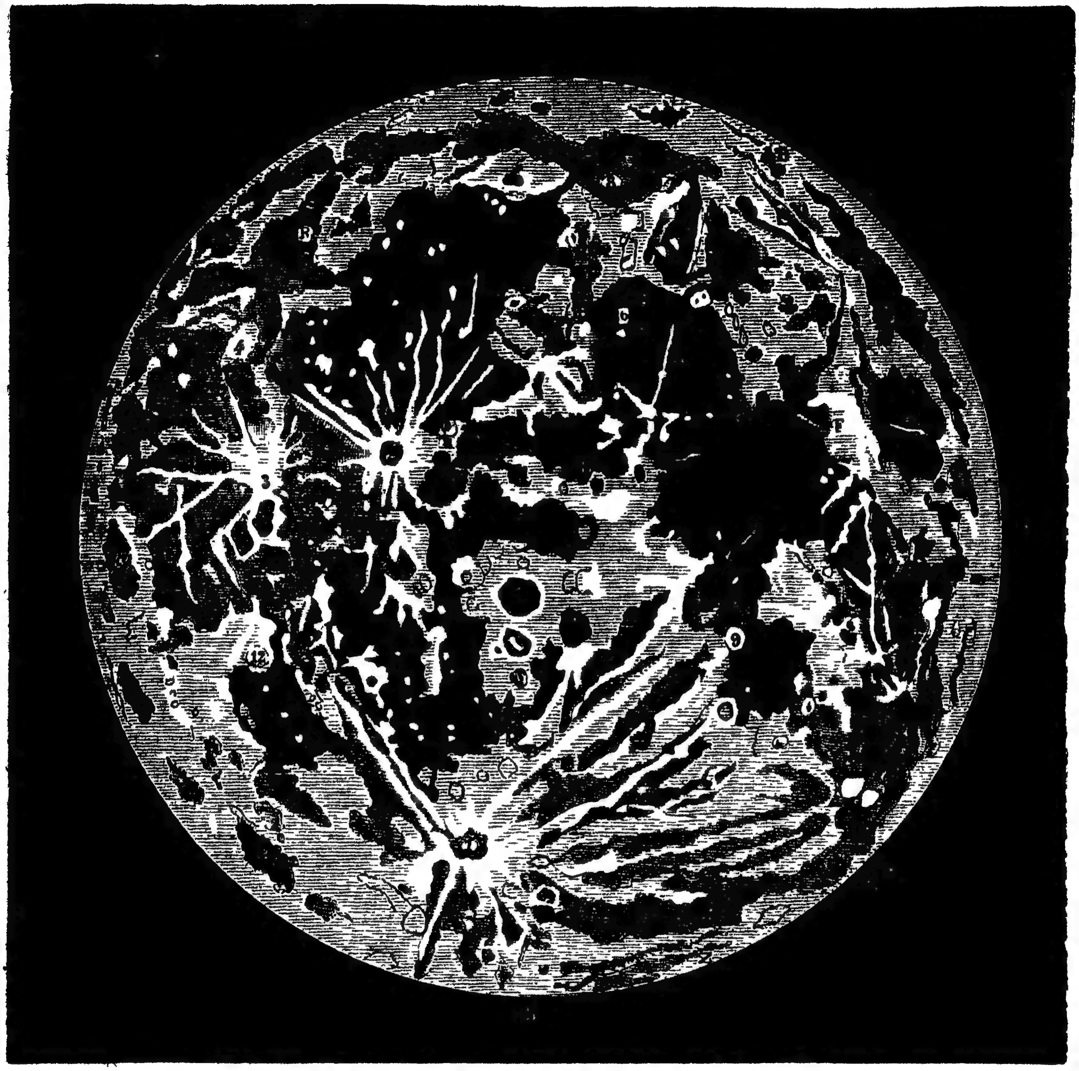

Fig. 2.—A MAP OF THE MOON AS SEEN IN AN ORDINARY TELESCOPE

LUNAR SEAS OR GREY PLAINS.

A. The Sea of Crises (*Mare Crisium*).
B. Humboldt's Sea (*Mare Humboldtianum*).
C. The Sea of Cold (*Mare Frigoris*).
D. The Lake of Death (*Lacus Mortis*).
E. The Lake of Dreams (*Lacus Somniorum*)
F. The Marsh of Sleep (*Lacus Somnii*).
G. The Sea of Tranquillity (*Mare Tranquillitatis*)
H. The Sea of Serenity (*Mare Serenitatis*).
I. The Marsh of Fogs (*Palus Nebularum*).
The Marsh of Corruption (*Palus Putredinis*).
L. The Sea of Vapours (*Mare Vaporum*).
M. Mid-Moon Bay (*Sinus Medii*).
N. The Bay of Tides (*Sinus Æstuum*).
O. The Sea of Showers (*Mare Imbrium*).
P. The Bay of Rainbows (*Sinus Iridum*).
Q. The Ocean of Tempests (*Oceanus Procellarum*).
R. The Bay of Dew (*Sinus Roris*).
S. The Sea of Clouds (*Mare Nubium*).
T. The Sea of Liquids (*Mare Humorum*).
V. The Sea of Nectar (*Mare Nectaris*).
X. The Sea of Fecundity (*Mare Fœcunditatis*).
Z. The Southern Sea (*Mare Australe*).

LUNAR RING-MOUNTAINS AND CRATERS.

1. Tycho.
2. Copernicus.
3. Kepler.
4. Aristarchus.
5. Plato.
6. Linné.
7. Archimedes.
8. Aristotle.
9. Theophilus.
10. Ptolemæus.
11. Schickard.
12. Gassendi.
13. Grimaldi.

peculiar character or tint. When I speak of them as plains, I do not wish it to be understood that they are perfectly level. There are portions of some of these seas which seem as level as the smoothest prairies in America; others are more like the rolling prairies; all show signs of having a rough real surface. But they are plains in the same sense that any wide districts of our earth where the variations

of height above the surface do not amount to more than a hundred feet or so, are spoken of as plains. The general idea conveyed by their appearance under the telescope is that they are old sea-bottoms; some older, which have undergone upheavals and other changes since the water retreated from them, others presenting the appearance of being unchanged since the time when, after depositing layer upon layer of earthy matter, the waters dried up, or were in some other way removed. These peculiarities of surface contour, and the fact that the low level plains are darker than the high mountain regions, are highly significant. They seem to me to speak unmistakably of long eras of time during which water existed on the moon, and enormous quantities of earthy matter like those which form the darker "rocks" of our own earth were deposited at the bottom of the lunar oceans, seas, and lakes, while wide tracts of alluvial matter were formed at the mouths of the chief lunar rivers.

The map of the moon forming Fig. 2 represents her as she appears in an ordinary telescope for viewing landscapes, &c., so that she is not inverted as with the astronomical telescope.

The two eyes are formed by the Sea of Showers (O), and the Sea of Tranquillity (G). The latter is to the eye the darkest large tract on the moon's surface, though in photographs of the full moon the Sea of Serenity (H) appears quite as dark. The Sea of Vapours (L), the Bay of Tides (or Heats) (N), and Mid-Moon Bay (M), form the nose, whose somewhat "tiptilted" form is outlined by a range of mountains bounding the Sea of Showers on the S.W., and called the Lunar Apennines. The mouth, rather wide and gaping, is formed by the Sea of Clouds (S). The rest of the face can be filled in by the imagination *ad libitum.*

If the telescope gives evidence of the past action of water on the moon, much more clearly does it bring into view the signs of former igneous activity. I have mentioned the Lunar Apennines. Ranges such as these are not the most remarkable features of lunar mountain scenery. The lunar mountain chains show, like those of the earth, a greater steepness on one side than on the other—the side towards the so-called seas being the steepest, precisely as the Pacific slopes of the Andes and Rocky Mountains and the southern slopes of the Himalayas are steeper than the slopes tending to the wide extent of continent on the east of the American and on the north of the Asiatic chains. Scattered mountains, hills, and rocks are numerous, some of them standing on the plains in solitary grandeur. According to some observers the steepness of the sides of some of these detached elevations is only equalled among the terrestrial regions most remarkable for the height and abruptness of their mountains.

But the most remarkable of all the lunar features are the ring-mountains, or great craters. These are not only much larger relatively to the moon's smaller globe, but much larger absolutely, than the largest craters on our own earth. They also are differently shaped. Terrestrial craters are usually comparatively small openings at the top of large conical mountains. In the moon, the raised ring surrounding the crater rises to a relatively small height above the surrounding slopes and the enclosed flat bottom, while some of the chief craters have a span of many miles. Astronomers commonly arrange the lunar ring-shaped cavities into three classes—"Walled Plains, Ring-Mountains, and Craters." The walled plains appear to have been formed first by volcanic fires, upheaving a large region, and forming all round it a ring of raised rocky matter, while later the interior seems to have been invaded by liquid matter from without, carrying in and depositing substances of the same kind as those which form the surface of the so-called seas. The ring-mountains are smaller, and the craters yet smaller. Some observers add, as a fourth class, small saucer-shaped depressions not girdled by a ring raised above the surrounding plain.

The thirteen ring-mountains and craters numbered in our picture will suffice to give a good idea of these remarkable objects.

No. 1 is the great circular mountain Tycho, which may be compared to a great carbuncle on the chin of the man in the moon. It is the centre of a wonderfully irregular mountain region, over which lie hundreds of craters and ring-mountains, while from Tycho itself radiations extend in all directions, some reaching to enormous distances. Nasmyth compares these to cracks in a globe which has been burst by the expansion of matter within it, or (which comes to the same thing, and probably corresponds more closely with what has actually happened in the moon's case) by the contraction of the globe upon unyielding matter within. It has been objected to this view, that if the shell of the lunar globe was burst in this way, the cracks would not have closed so exactly that no shadows would be thrown along them; and no shadows are seen along the streaks of bright surface radiating from Tycho. But it appears to me, that if through the mighty openings thus formed liquid lava were

poured out, it would flow all over the opening along the cracks, and would have, while liquid, and retain after cooling, a nearly level surface throwing no perceptible shadows. At any rate, there seems no other way of accounting for the radiations from Tycho and a few other craters, than one involving the action of volcanic forces; and Nasmyth's cracked globe theory seems to indicate the most natural way in which such radiations could be accounted for. The wall of Tycho rises to a height of nearly three miles, or more exactly about 16,600 feet,—greater than the height of Mont Blanc. The diameter of the circular enclosed space is nearly 50 miles, so that the area of this space is about 2,000 square miles. In the middle there is a mountain about 5,000 feet high.

The crater Copernicus (2) is still larger than Tycho, having a diameter of 56 miles. Its central mountain, which has six heads, attains in its two highest heads a height of about 2,400 feet. It is manifest from the appearance presented by this crater as the boundary between the light and dark parts of the moon passes over it, both in advancing and in retreating, that the whole crater stands high above the mean level of the moon's surface. In this respect it seems to be an even more important formation than Tycho, though the radiations from Copernicus do not extend so far as those from Tycho. Under full illumination Copernicus appears as a large, ill-defined white patch (on the left of the man-in-the-moon's nose). The floor of Copernicus is about 11,000 feet below the ridge of the surrounding ring.

Before passing from this important and characteristic lunar crater, it may be well to notice that, while the radiations from Copernicus illustrate Nasmyth's theory of the action of the nuclear matter upon the contracting crust of the moon, the region around Copernicus illustrates in another way a later process, which has left almost equally well-defined traces of its action. If we consider the moon at that particular stage of her past history when a continuous crust had first formed around the molten matter forming her nucleus, we perceive that there would be two well-marked periods of progress from that stage. During the first, the outer crust would cool more rapidly than the nucleus, because radiating its heat freely into space. Consequently, the crust would contract upon the nucleus, and from time to time would be compelled to give way at various points of its extent, a series of radiating cracks appearing round the region where the crust had yielded. But after a time, the crust, having already greatly cooled, would no longer cool so rapidly. The heat poured from it into space would be compensated, or nearly so, by the heat which it would receive from the cooling nucleus. Thus the nucleus would now in its turn cool more rapidly than the crust. The nuclear matter would therefore shrink from the crust, which, yielding to the action of lunar gravity, would contract in such a way as to form surface corrugations. Nasmyth mentions the shrivelled skin of a dried apple and the wrinkles of loose skin upon a lean and shrunken hand as illustrations of the corrugations thus formed. Now, over the region around Copernicus the corrugations of the lunar crust are singularly well shown. Whether it be that the same circumstance which causes the crater itself (to its very base) to be far higher than the mean level of the moon's surface, has favoured the formation of these corrugations, or whatever may be the true explanation, certain it is that they are especially numerous, complex, and well defined, over the whole region around this fine crater.

Another interesting peculiarity of the moon's surface is well shown in the region around Copernicus—the immense number of small craters. I have sometimes been disposed to believe that some among these—at least some among the smallest craters—may have been produced by a cause quite different from that to which unquestionably all the large craters, and most even of the small craters, must be assigned. When we remember that even at this day millions of meteoric masses, of greater or less size, fall upon our earth every year, and that necessarily more than one-fourteenth as many fall on her companion planet the moon (which presents to matter outside a surface equal to rather less than one-thirteenth of the earth's), we perceive that in remote ages, when as yet the supply of meteoric matter had not so nearly approached exhaustion, the downpour of meteors on both the earth and the moon must have been far heavier than at present. Combining this consideration with the circumstance that during many thousands of years the moon's crust must have been so heated as to be plastic to receive impressions from without, yet firm enough to retain them, it can scarcely be doubted that the moon's surface must show some marks due to the downfall of the larger meteoric masses in that long period of her past existence. Any one who studies carefully the region around the lunar crater Copernicus with a powerful telescope, will not fail to recognise many minute pits, whereof some, at least, may fairly be explained

as due to the downfall of meteors of the larger sort.

Kepler (3), a crater about 22 miles in diameter, is the centre of another great ray-system intersecting that of Copernicus in such a way as to suggest that Kepler is the later formation. The interior is depressed about 10,000 feet below the top of the ring.

Aristarchus (4) is a ring-mountain about 28 miles in diameter, the ring rising some 7,500 feet above the floor. Within is a mountain of singular whiteness. The ring being also very bright, the entire crater is visible to the naked eye as the brightest small spot on the moon's face, Copernicus being, however, on the whole more conspicuous. In the telescope the central mountain can be seen even when it lies well within the dark part of the moon's disc. Sir W. Herschel mistook it, under these circumstances, for a volcano in eruption, but doubtless the light with which it then shines is simply reflected earth-light. For it must be remembered that the earth shines in the skies of the lunarians as an orb more than thirteen times larger than the moon appears to us, and probably giving nearly twenty times as much light.

Plato (5) is one of the most interesting of the lunar ring-mountains. It was formerly called the Greater Black Lake, on account of the darkness of the enclosed plain. This plain is nearly circular, about 60 miles in diameter, and containing about 28,000 square miles. The ringed wall varies in

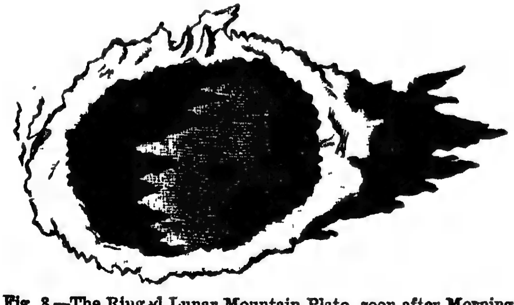

Fig. 3.—The Ringed Lunar Mountain Plato, soon after Morning there.

height from 3,800 to about 7,300 feet on the western side, attaining on the eastern side a somewhat greater height. The floor is not uniform in tint, but, as shown in Figs. 3 and 4, presents slight variations, and contains several small craters. It has been supposed by some observers that the floor of Plato grows darker as the sun rises higher above its level. But the general opinion, at present, among astronomers, is that the supposed change is merely an effect of contrast. If we compare Figs. 3 and 4, one showing the ringed plain soon after morning has begun there, the other showing it at the time of lunar mid day, we see how in the former case (and similarly towards eventide) the black

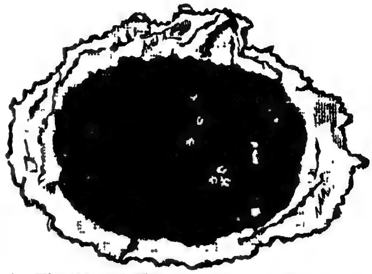

Fig. 4.—The Ringed Mountain Plato at Mid-Day there.

shadows cause the floor to look bright by contrast, whereas at mid-day in Plato the bright ring all round the floor causes the latter to look dark.

Linné (6), in the Sea of Serenity, is a much smaller object, but even more interesting. It was described by Lohrmann as "very deep," and by Beer and Mädler as "deep;" but in 1866 Schmidt noticed that Linné appeared as a mere whitish cloud. There seems (after considerable conflict and discussion) to remain little doubt that in some way, as yet not explained, the walls of this deep crater have been lately in great part prostrated.

Archimedes (7) is a spot not unlike Plato in size and shape, but presenting none of the peculiarities or seeming changes of tint which characterise Plato.

Aristotle (8) is a fine crater 50 miles broad and about 10,000 feet deep.

Theophilus (9) is remarkable as the deepest of all the lunar craters. Its diameter is about 64 miles, and the walls around range from 14,000 feet to 18,000 feet in height above the floor. There is a central mountain more than 5,000 feet high.

Ptolemæus (10) is the most northerly and the largest of a chain of ringed plains. It is no less than 115 miles in width.

Schickard (11) is an enormous walled plain 460 miles in circuit. Though the ring is in parts 10,500 feet high, it must be quite invisible from the middle of the plain, owing to the convexity of the moon's surface.

Gassendi (12) is a walled plain about 55 miles across; Grimaldi (13) is a great crater 147 miles long by 129 broad, and remarkable as having a floor darker than any portion of the moon of similar size. It can be seen, under favourable conditions, without a telescope.

Besides the features hitherto considered, the moon's surface presents under close telescopic scrutiny a number of valleys, ravines, gorges, and clefts, or rills. Some of these last are very singular in character. As Webb remarks, they "pass chiefly through levels, intersect craters (proving a more recent date), reappear beyond obstructing mountains as though carried through by a tunnel, and commence and terminate with little reference to any conspicuous feature of the neighbourhood. The idea of artificial formation is negatived by their magnitude; they have been more probably referred to cracks in a shrinking surface." There are also closed cracks, sometimes of considerable length, where the surface is raised higher on one side of the crack than on the other, so that the displacement (of the same nature as what is called by miners a *fault*) can be recognised by the shadow thrown on the lower side.

From all the observations hitherto made upon the moon, it appears that she has a very thin atmosphere. When she passes over the stars these disappear and reappear quite suddenly; not fading gradually from view and coming as gradually into view again, as they would if the moon had an atmosphere of appreciable density. The absence of any atmosphere, save one of extreme tenuity, is also shown by the blackness of the shadows of the lunar mountains, and by other phenomena which need not here be considered.

As there are no signs of water on the moon's surface, we may reasonably conclude that her globe, waterless and airless, cannot possibly be the abode of any forms of life resembling those with which we are familiar on this earth.

The opinion has been entertained that on the farther and invisible part of the moon there may be air and water, and consequently that living creatures may exist there. But though there are many reasons for believing that the moon has not always been a waterless and airless globe, it is no longer supposed that her air and water have retreated to the farther side. The opinion more generally entertained is that as the moon's interior cooled, the water formerly filling the lunar seas and bays retreated to the interior of the moon; not filling cavities there (for cavities cannot exist in the interior of so large a globe), but soaking the moon's substance in the same way that water soaks the substance of pumice-stone and similar materials.

But it must be admitted that while the evidence showing the moon to be airless and waterless is clear, and while there are strong reasons for believing that the moon once had seas and probably an atmosphere much denser than her present atmosphere, it is not at all easy to form a satisfactory theory respecting the processes by which she attained her actual condition.

From observations which have been made with a view to determine the tint (irrespective of *colour*) of the moon's surface, it appears that while the average reflective capacity of the moon is about the same as that of weathered sandstone, the grey plains are much darker, the bright raised regions much whiter. The darkest parts are as deeply tinted as our darkest earth, and the brightest spots almost as white as lately-fallen snow. From the way in which the amount of the lunar light varies as the moon passes through her various phases, it is believed that her entire surface, even the parts which appear smoothest, are in reality altogether rugged.

To sum up what we have learned about the moon: We find that she is a planet accompanying a larger planet, the earth, on its journey round the sun. Her diameter is about one-quarter, her surface about 2-29ths, her volume about 2-99ths, her mass about 2-163rds of the earth's. She completes a journey round the earth regarded as at rest in about 27⅓ days, travelling at a mean distance of 238,820 miles; but the lunar month, or the period between successive conjunctions of the sun and moon, has an average length of about 29½ days. The moon's surface may be divided roughly into raised parts which are usually bright, and great plains (not smooth) which are darker, and in some cases very dark. Over all the raised parts the signs of former volcanic activity are very marked, craters and ring-mountains, much larger than any existing on the earth, being found in great numbers on the moon's surface. Smaller craters are numerous, not only in the raised parts but over the grey plains. Cracks and faults, deep valleys, ravines, and gorges, are also numerous on the rugged surface of our satellite. No water and very little air seem present on the moon; though there are signs that seas formerly existed there, and there is reason to believe that the lunar air was once not very rare. Although all is not at rest in the moon, and certain portions of her surface seem to have undergone remarkable changes, even in recent times, there is nothing to suggest that our satellite is at present the abode of life.

# A PIECE OF LIMESTONE.

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MANY of my readers may have had the good fortune to spend a holiday in one of the great limestone districts of England—say in Derbyshire, in north Lancashire, in the south-west of Westmorland, or in the West Riding of Yorkshire. Those who have done so, will be willing to endorse the statement that there are few fairer regions in our own fair country. The high and breezy uplands are studded with masses of bare grey rock, seamed by deep and regular fissures, in the cool shade of which flourish miniature forests of snaky hart's-tongue, or delicate bladder-fern. All round the tops of the hills run great terraces of gleaming limestone, and their slopes are covered with short, crisp grass of the brightest green. In the hollows grow clumps of spreading trees, in delightful contrast to the white and glaring roads. Every here and there springs of water well forth out of the ground; and the clear brown streams make their way down to the sea through deep and narrow gorges, dashing themselves into foam over rocky ledges or wearing their stony beds into a thousand fantastic shapes.

In some of the more typical limestone districts—such as Derbyshire, Gloucestershire, or Somersetshire—we might find a thickness of from one to perhaps three thousand feet of pure limestone, with hardly any intermixture of other kinds of rock. In other localities, as in Westmorland, Cumberland, Lancashire, and Yorkshire, we should find numerous beds of limestone, amounting in the aggregate to a great thickness, separated by beds of sandstone and shale. In the latter case even a superficial observer would recognise the limestones, from the fact that they stand out boldly as prominent "scars," the intervening slopes being occupied by the softer rocks with which they are associated

Apart, however, from its scenic effects, limestone is one of the most useful and important of all the substances which enter into the composition of the crust of the earth, and it is well worth our while to know what limestone *is*, and how it was produced. Some dry details have necessarily to be faced before we can answer these questions fully, but we shall find that the history of limestone is, for all that, one of great and far-reaching interest.

The first thing we have to do is to procure a piece of limestone—a feat of very easy accomplishment in almost any part of this country. If we have obtained a specimen of any ordinary limestone, we shall find that we have a greyish or bluish rock, sometimes nearly white, sometimes black, sometimes pink, or brown, of a hard, compact texture. The broken surfaces of the piece often look somewhat crystalline—that is to say, we can see that the rock is to some extent composed of separate crystals, much as in loaf sugar, though to a much smaller degree. At other times the texture of the rock is extremely close and fine-grained. As a general rule, the naked eye will tell us nothing more about limestone than the above, though there are cases in which we might learn more.

If we wish, however, to unravel the history of limestone, we must go much deeper than the eye alone would lead us, and we must ask the assistance of several branches of science. Let us first see what we can learn as to the chemical nature of limestone, a point of fundamental importance, both from the scientific and the commercial aspect of the question. If we take a piece of limestone, and heat it strongly in a furnace, we find that it becomes much lighter in colour, and much more friable—or crumbling—in texture, and we find further that though apparently unaltered in bulk, it has lost a considerable portion of its weight. It now possesses properties which are quite different to those of limestone itself, and it is generally known as "quicklime." The chemist will tell us that quicklime is *lime* properly so called; so that we have here *one* of the constituents of limestone. What, however, has the limestone lost which would account for its decrease of weight and change of properties in its conversion into quicklime? It has lost, as we could easily convince ourselves, two things, both of which were expelled from the furnace by the heat, in a form invisible to the eye. One of these is *water*, driven off as steam or vapour by the heat. The other is the transparent gas, with which we are so familiar as the aërating agent in soda-water or lemonade, and which chemists call *carbonic acid.* This gas is also driven off by the heat; and the danger of sleeping near a lime-kiln, as many a homeless wanderer has found, arises from the fact that its fumes are poisonous.

In technical language, then, limestone is a compound of lime and carbonic acid, or is a

carbonate of lime, containing a certain amount of water, and mixed with a greater or less amount of various impurities, such as clay, silica, iron, &c. When we heat limestone, we drive off the water and the gas, and the lime is left behind, along with all non-volatile impurities. This fact is at the bottom of the process of lime-burning.

Whether pure or impure, whether artificially prepared by the chemist or under the numerous natural forms of limestone, carbonate of lime possesses one property which is of great importance as bearing upon the question of the origin of limestone. It is, namely, capable of being to a greater or less extent dissolved by water impregnated with carbonic acid. All natural waters contain more or less of this gas, and carbonate of lime is one of the commonest of minerals. Hence almost all spring-water contains more or less of carbonate of lime in solution, a fact which we express by saying that the water is "hard." The water of the sea also has a certain amount of lime dissolved in it, and so have the waters of rivers and lakes. In some cases—especially in the instance of springs in volcanic districts, the waters of which are highly charged with carbonic acid—the amount of lime held in solution in the water is extremely large. When such lime-impregnated waters, however, are exposed to the air, their carbonic acid escapes, and the lime, deprived of its natural solvent, is thrown down in its original solid form. It is not uncommon, therefore, to find great beds of limestone which have been produced in this way at the points where springs of this kind break forth at the surface. Similar but smaller deposits of lime are commonly formed by the springs, or rivers, of limestone districts, as shown by the familiar phenomenon of "petrifying springs." The long pendants of carbonate of lime (stalactites) which hang from the roofs of caves, or decorate the joints of the mortar in old bridges, and the layers of lime (stalagmite) thrown down on the floors of many limestone caverns, are further instances of the deposition of lime directly from water holding it in solution.

Though the formation of limestone by direct chemical action is thus a common one, nevertheless we cannot ascribe the production of any of the more important masses of limestone which we find in the crust of the earth to any process of this kind. Chemical action there still is; but it is chemical action controlled and modified by the potent magic of the living organism. We have seen that the waters of rivers, lakes, and seas contain a certain amount of carbonate of lime in solution, invisible to the eye, and without form. Think now how many of the animals and plants inhabiting these same waters possess more or less elaborate skeletons of lime. The beautiful shells of our ordinary shell-fish, the exquisite envelopes of the microscopic *Foraminifera**—the minute shells of which are found in the sands of the sea-shore or in the ocean ooze—the armour of crabs and lobsters, and other wrongly-called "shell-fish," the prickly cases of the sea-urchins, and the skeletons of many other aquatic animals, are formed of carbonate of lime, wholly or in great part. The link between these two facts is direct and unavoidable. All living beings inhabiting water and possessing a skeleton of lime, derive the material of that skeleton directly from the water in which they live. Hence, though the rivers are constantly carrying down to the ocean the carbonate of lime which they hold in solution, the undue increase of this substance in the water of the sea is prevented by the equally constant appropriation of it by myriads of marine animals, which again reduce the lime to its solid form, and store it away in their tissues, giving it at the same time the unmistakable stamp of *organic form*.

Fig. 1.—A living Sea-lily or Crinoid, showing the Head and Upper Part of the Jointed Stem.

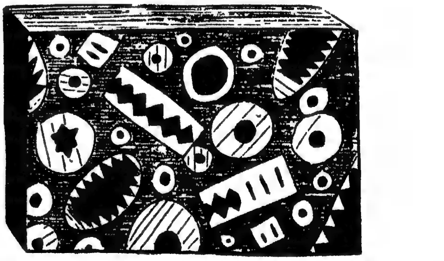


Fig 2.—A small Piece of Limestone, cut and polished, showing the Stems of the Crinoids cut across.

Let us now apply the above facts to the solution of the problem as to the origin of limestone; and to do this thoroughly we must look at limestones from different localities, or from different beds in the same locality. We cannot do better than look in

* The *Foraminifera* are animals of an exceedingly low grade, composed of apparently structureless living matter, with almost no definite organs, but capable of producing for themselves a beautiful, and often mathematically regular, shell of lime. Most of them are so small as not to be visible except under the microscope, and for this reason they have unfortunately never received any popular name. Small as they are, the sand of the sea-shore is often largely made up of their shells.

the first place at a piece of one of the "marbles" of Derbyshire, merely premising that a "marble" is nothing more—necessarily, at any rate—than a limestone which is hard enough to take on a brilliant polish. Such a limestone, especially when seen in polished slabs, is found to be composed of little else than the calcareous stems of the animals which naturalists know as the sea-lilies or crinoids (Fig. 1). A few of these beautiful animals, resembling small star-fishes rooted to the sea-bottom by a long jointed stalk, are found living in the depths of our present seas, but their numbers are very few. Here, however, in Derbyshire, and indeed in many other parts of Britain, we have whole beds of limestone, of great thickness, and covering vast areas, composed of nothing more than an aggregation of

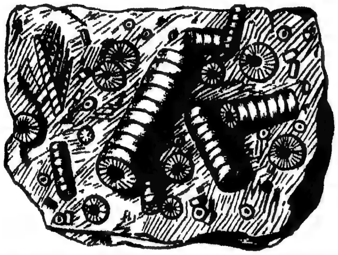


Fig. 3 —A small Piece of Limestone, showing numerous Fragments of Crinoids on its weathered Surface

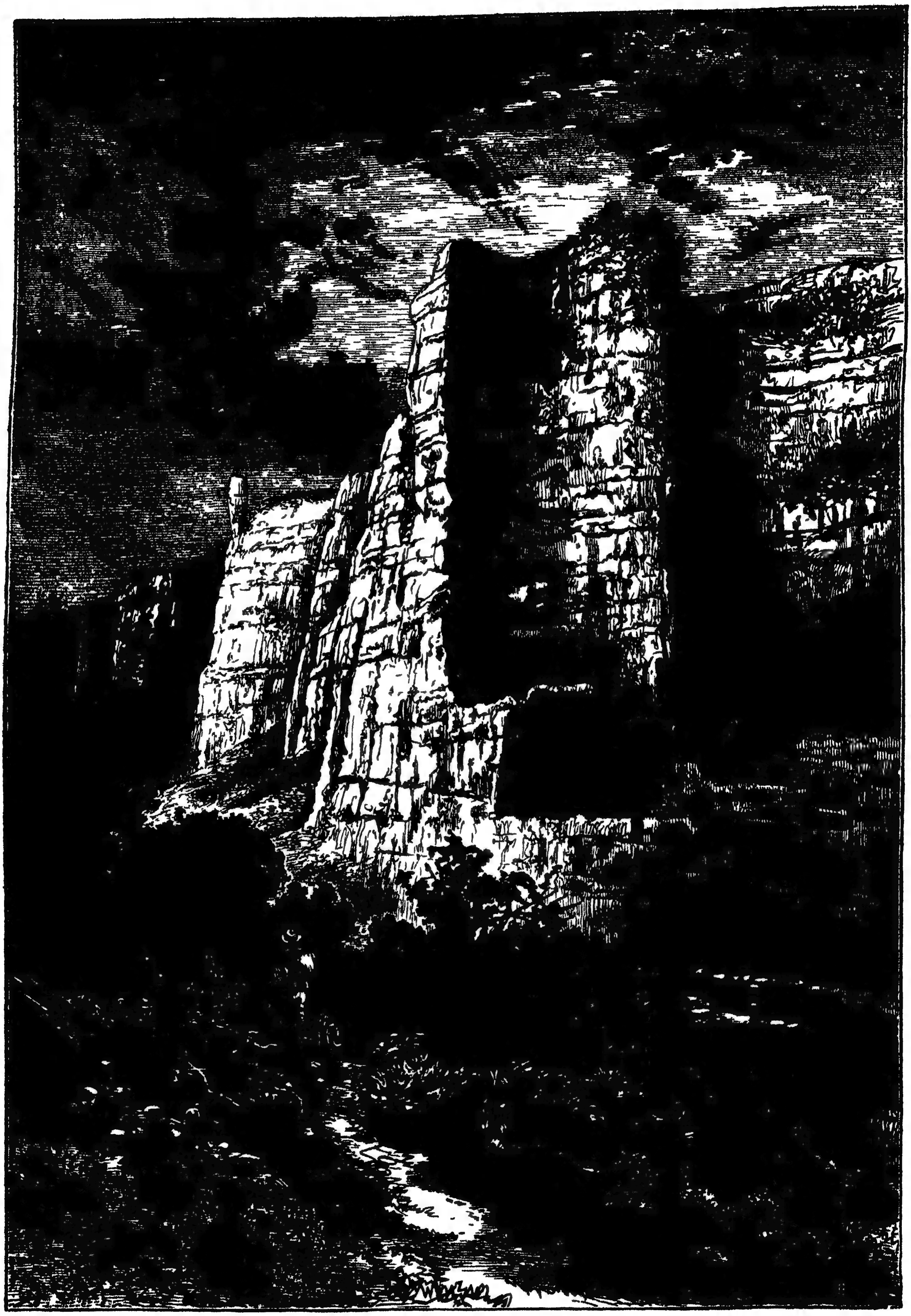
the broken stems of these elegant creatures, all bound together by a calcareous cement (Figs. 2 and 3). Now, all known sea-lilies are denizens of the sea, and it is therefore a matter of certain deduction that the beds of Derbyshire marble, and all other limestones of a similar character* in other places, existed at one time in the form of great banks and forests of these animals in a *living* condition. They were either formed by the growth of successive generations of crinoids, *in place;* or they were formed by the heaping up by the waves and currents of the sea of vast accumulations of their skeletons in a more or less broken and fragmentary condition.

Here is another piece of limestone, again, which is composed of the skeletons of coral polypes, in all essential respects similar to the coral-producing zoöphytes of recent seas; and entire beds of the limestone are made up of these beautiful structures, often standing erect, as they originally grew on the sea-bottom. In this case not only do we know that the limestone was formed beneath the waters of the sea (all known corals being marine), but we are fortunately enabled to point to precisely similar limestones now in process of formation. If we transport ourselves to the West Indies, the Pacific, or the Indian Ocean, we find that vast deposits of limestone are now being laid down in the sea, in the form of coral reefs. These cover enormous areas, and may be continuous for hundreds of miles, and they are composed principally of the calcareous skeletons of the beautiful coral polypes—animals resembling the sea-anemones in fundamental structure, but capable of secreting for themselves a calcareous support or framework, over which their soft and brilliantly-coloured bodies are spread. Whilst parts of the reef are composed of the skeletons of the corals standing erect as they grew, other parts are made up of broken-down corals, which have been reduced to fragments by the waves of the sea, mixed up with shells of all kinds, and often with the limy skeletons of sea-weeds. These accumulations of calcareous *débris* soon harden into solid rock, and then reproduce for us, in almost every particular, the ancient coralline limestones with which the geologist is so familiar. In the case of these latter limestones, then, as in the case of the crinoidal limestones, we have a certain proof that the rock was formed beneath the sea, and that it is essentially composed of the skeletons of living beings.

Here, again, is another piece of limestone which is full of different kinds of shells, for the most part quite perfect. In this case, the *organic* origin of the rock is as clear as in the preceding instances, but the rock would not necessarily have been formed in the sea. Some limestones contain shells which resemble our living oysters, mussels, whelks, cockles, periwinkles, &c., and such are all of marine origin, since these shells all inhabit salt water. Other limestones, again, are full of the remains of shells which so closely resemble our living river-mussels and pond-snails as to leave no doubt that their habits of life were the same. These limestones, therefore, were formed in fresh water, and are composed of the skeletons of animals which lived in rivers or lakes.

The three pieces of limestone which we have hitherto been examining all contain the whole or broken skeletons of animals large enough to be conspicuously visible to the naked eye. Not only is their size considerable, but the skeletons in question are so obviously identical with the skeletons of now living animals that the only wonder is that they should have been so long passed over—as they still are by many who have

* As the sea-lilies are technically called "crinoids" or "encrinites," it is usual to speak of all limestones which are composed of their skeletons as "crinoidal limestones" or "encrinital limestones."



Limestone Rock, Middleton Dale. Derbyshire.

not learned to use their eyes—or that their animal nature should ever have been doubted; this last feat, however, having only been accomplished by people who did not *want* to believe that they could be the remains of beings that were once alive. So far, then, it is tolerably plain sailing; but there are very many specimens of limestone in which you would find few or none of these conspicuous animal remains, such as sea-lilies, corals, or shell-fish, and the whole or the greater part of the rock would appear to the unassisted vision to be simply compact and structureless. At this point of our inquiry we have to call to our aid an instrument the full value of which in geology has only recently been recognised—namely, the microscope. We cannot, of course, obtain much benefit by simply placing a piece of limestone under the microscope, though sometimes something may be done even in this way. It is not, however, a matter of great difficulty, by processes which need not be further alluded to here, to obtain a slice of limestone (or of any other rock) so thin that it can be seen through with the greatest ease. By this means we can render the magnifying power of the microscope readily available in the elucidation of the intimate structure of the most dense and compact of rocks.

If, then, we take such a transparent slice of any ordinary compact limestone, which shows few or no indications of its containing animal remains, so far as the naked eye is concerned, what do we see on

**Fig. 4.—Part of a thin Slice of Limestone (Carboniferous) as seen under the Microscope, showing that the Rock is almost wholly made up of Animal Remains.**

submitting this to the microscope? As a general rule, we should find that the apparently structureless mass is instinct with the traces of bygone life. Instead of a mere crystalline or granular aggregate, our eye would delightedly recognise innumerable fragments of the skeletons of all kinds of marine animals, such as sea-lilies, or corals, along with, in many instances, entire and beautifully-shaped microscopic shells, the whole bound together into a solid mass by a calcareous cement (Fig. 4). We should therefore have no difficulty in recognising that the rock is really of *organic* origin, and that it is composed of the minute skeletons of microscopic animals, or plants, or of the fragments of the skeletons of larger forms.

We ought, however, to go further than this, and our demonstration would not be regarded as complete unless we could point to some similar limestone now in process of formation in our own seas. The "coral rock" of many coral islands is largely composed of microscopic calcareous organisms, or of the broken-down *débris* of the skeletons of larger beings, and therefore in part supplies us with the parallel we want; but we may find a better example still. Everybody knows the soft, earthy white limestone which we generally call chalk. Let us see what modern science has taught us as to the real nature and constitution of this substance, long one of the puzzles of the geologist. The white chalk covers an immense area in Europe, and attains a thickness at times of a thousand feet, and as it is throughout composed of more or less soft and powdery carbonate of lime, it is no matter for astonishment that the older geologists felt a difficulty in bringing forward any satisfactory theory as to its origin. From this difficulty they were relieved by the microscope on the one hand, and on the other hand by those marvellous investigations which have of late years been carried out as to the nature of the sea-bottom at great depths. If you make a thin slice of chalk sufficiently transparent to be seen through, and examine that by means of the microscope, you will find that instead of being composed merely of grains of carbonate of lime, as we might expect, it is really made up of fragments of the skeletons of various marine animals, mixed with innumerable chambered calcareous shells of microscopic size, the whole united together by a granular calcareous base. The little chambered shells just spoken of belong to the minute animals which the zoologist calls *Foraminifera*, and though of common occurrence in many of the ordinary limestones, it is not often that they are found—as in chalk—in such numbers as almost to compose the entire rock. Chalk, in fact, may be properly described as a soft *foraminiferal* limestone, since these minute and beautiful shells are the principal element in its composition (Fig. 5). We have, therefore, to begin with, to endeavour to adequately comprehend the wonderful fact that we have in the chalk a rock occupying hundreds of

square miles, and attaining hundreds of feet in thickness, which is essentially composed of the calcareous envelopes of animals so small as to be absolutely invisible to the naked eye. For our knowledge of the modern representative of the

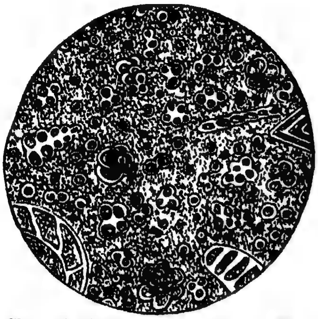


**Fig. 5.—A thin Slice of Chalk as seen under the Microscope, showing that the Rock is composed of minute Shells (*Foraminifera*) imbedded in a granular Basis of Lime.**

chalk we are indebted mostly to the deep-sea soundings carried out in H.M.S. *Cyclops* for the purpose of finding a suitable track for the Atlantic cable, and later to the deep-sea dredgings prosecuted in the *Lightning*, *Porcupine*, and *Challenger* expeditions, which were sent out for the purpose of clearing up our ignorance as to a great many points connected with the condition of the ocean and its bed at great depths. From these, as well as other sources of information, we know that there is now forming in the abysses of our great oceans a deposit which is essentially similar to unconsolidated chalk. This deposit, often called the "Atlantic ooze," is found at great depths in both the Atlantic and Pacific Oceans, covering areas of vast extent, and presenting itself as a whitish-grey, impalpable mud, very like greyish chalk, when dried. Chemical examination shows us that this ooze is composed almost wholly of carbonate of lime, and the microscope reveals the fact that it is principally made up of the microscopic chambered shells of *Foraminifera*, many of these being absolutely indistinguishable from the *Foraminifera* of the chalk. If, therefore, the Atlantic ooze were once consolidated and converted into rock, it would present us with an almost complete parallel to the true white chalk of geologists.

Chalk, then, is only another example in support of the general statement that the majority of limestones are of organic origin, and are composed of the calcareous skeletons of animals and plants. Of the truth of this general statement we can have no doubt whatever, for it admits of direct demonstration ; but there are some cases in which we must of necessity rely upon analogy simply. The only case of this nature which needs to be alluded to here is that of the hard and crystalline limestones which constitute most, though by no means all, of our ornamental marbles. If we look, for example, at the beautiful white statuary marbles of Carrara, we should fail to find any direct proof that they were of organic origin. The microscope would show them to be composed of nothing but smaller or larger crystals of carbonate of lime confusedly mixed together, just as a lump of loaf-sugar is made up of crystals of sugar. We have, however, every reason to feel sure that these crystalline marbles were at one time nothing more than ordinary limestones, and, like these, were originally composed of the skeletons of various animals. They lost their primitive condition, and assumed their present crystalline state, in consequence of their having been subjected to the action of heat combined with pressure, as the effect of which the particles of the rock underwent a complete rearrangement, assuming a crystalline form, and thus necessarily obliterating all traces of their original organic nature. That this is no mere theory is proved by the fact that in some crystalline marbles the change above spoken of has not affected all parts of the mass equally, so that in places we may find the rock less affected than elsewhere, and here we may meet with organic remains. Another proof of the correctness of this view is afforded by the phenomena observed when any ordinary limestone comes in contact with a mass of rock (such as a bed of lava) which we can show to have been at one time in a melted condition. In such cases the limestone in the immediate vicinity of its once heated neighbour, is found to be converted into highly crystalline marble, and to have lost all traces of its original organic structure ; a little farther off from the lava it is hardened and perhaps slightly crystalline ; and still farther off again it has resumed its ordinary condition, and is crowded with the remains of animals.

Speaking broadly, then, we may regard it as established that the great masses of limestone which we find so largely developed in the crust of the earth are really of organic origin, and that a very considerable portion of the solid framework of our globe is thus composed of the calcareous skeletons of innumerable generations of animals and plants, many of which were individually of microscopic dimensions. Nor has this process of lime-making been confined to any one period of the earth's history, or to any one place on its surface. On the contrary, it has gone on ever since the first intro-

duction of life upon our planet, and it has occurred in all areas covered by the ocean. Hence we have limestones belonging to almost all the great geological periods, and forming a constituent of the land in all our great continents. We have, lastly, in the fact that limestones are composed of animal remains, a conclusive proof of the oscillations of level, the subsidences and the elevations, to which the apparently immovable dry land has been subjected at successive periods. The composition of the ordinary limestones out of the skeletons of marine animals is an incontrovertible proof that these rocks could only have been deposited beneath the waters of the sea. Every region, therefore, where we now meet with one of these marine limestones, must at one time have formed a portion of the sea-bottom. Every limestone thus marks, in the place where it occurs, a depression of the crust of the earth beneath the sea-level. On the other hand, every marine limestone which we now find forming part of the dry land, marks, at the point of its occurrence, an elevation of the crust of the earth above the sea-level by means of those great subterranean forces which are always at work over some portion or another of the earth's surface. Thus, an ordinary piece of limestone, such as we may pick up on any roadside, rightly considered, brings us at once in living contact with the slow but ceaseless action and interaction of those great natural forces by means of which the exterior of our planet has assumed its present structure and configuration.

# HUNGER.

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IS it not Mr. Carlyle who somewhere says that the two great moving powers of society are Hunger and the Policeman? Hunger impels people to eat. The policeman forces them to work for their food instead of stealing it. Thus, if we probe all human endeavour to the bottom, we shall find lying there an empty stomach. Although no small amount of very pretty writing has been expended on the "Dignity of Toil," and the "noble desire to be up and doing" that animates the natural man, it may fairly enough be doubted if such coruscations of rhetoric are based on any solid realities in human nature. Man does not toil because he thinks it noble to do so. The truth is rather that he looks on Labour as a sort of curse, which must be patiently borne, because it is one of the essential conditions of bare existence. Even so hard a worker as the late Mr. Thackeray declared that the worst defect he was born with was a strong disposition to easy-going indolence. The gentle "Elia," too, though a most industrious toiler, in some of his quaintest verses has put on record his natural hatred of work; indeed, he goes so far as to suggest it must have been one of the social nuisances invented by the devil. If all men were equally honest, we might find it generally accepted as an ultimate fact that man is naturally a lazy animal, averse to toil in every shape or form, loving above most things indolence as a delightful mode of human enjoyment. And what adds strength to this opinion is the curious fact, pointedly elucidated by the late Mr. Thomas Henry Buckle, that civilisation, the directest product of toil, usually appears soonest in regions where man has either to endure hunger or work in order to procure food. In the exuberant bounty of Nature may be found one of the primary causes of hopeless barbarism; simply because man is naturally lazy and uninventive when not spurred up by the sharp sting of famine. Place him in an environment where abundance of food comes to him without exertion, where a genial climate renders toiling with axe and spade unnecessary, and then, so far from working, he will be found sitting contentedly under the nearest tree, idly dreaming his life away in the sunshine. But he cannot do this in regions where subsistence has to be procured at the cost of labour; that is to say, in places which we are wont to call centres of civilisation. There most men—we might say all men—work, some honestly, and some dishonestly. If it be asked, What is it that engenders such an unnatural but beneficent practice—what is it, in other words, that is the cause of that whereof civilisation is the most direct and conspicuous product?—the answer is, Hunger. Now, what is hunger, and what are its causes?

Everybody knows by personal experience what the preliminary manifestations of hunger are like. On the other hand, very few people capable of

giving accurate and graphic literary expression to their sensations have any empirical knowledge of the sterner realities of hunger, when it develops into fierce starvation. The sensation experienced in the region of the stomach when one gets hungry is sharp, keen, but at the same time far from painful or unpleasant. It suggests not so much that one wants food, as that it would be enjoyed vastly if it could be got. Assuming that food is withheld, then we may say this sensation disappears in a varying time, and it gives place to a very different one. The feeling of keen appetite is replaced by a strange sense of stomachic vacuity, emptiness, or "sinking," to use popular terms, and this again gradually grows into absolute and clearly-defined pain. The inner surface of the healthy hungry stomach is of a paler tint than that which distinguishes the organ after the introduction of food, or whilst digestion is going on. Then the minute blood-vessels of the organ become injected with blood, and the tint of the surface changes from a light pink to a deep bright red. It is not easy to describe in words the sort of pain that hunger causes at this stage of abstinence from food, because it is scarcely possible to describe adequately in words any of the sensations connected with the "vegetative life" of man, or any of those set up by the working of the mechanism of nutrition. But, perhaps, the best way to realise the feeling of pain produced by prolonged hunger is to keep in view the fact that a sharp blow on the stomach will at any time cause the most acute agony, and to try and think what that suffering would be if, instead of having one's stomach struck, one had it clutched by two great red-hot iron hands, which kept on hour after hour tearing it into shreds and tatters. When this condition is reached, the human body may be fitly likened to the pelican in the ancient legend, that tore away its own vitals to feed its offspring. The frame of a man in an advanced stage of hunger preys upon its tissues in order to keep its organs in life. It is in the position of the struggling trader who "makes the two ends meet" by feeding his business not on profits, but on that to which it owes its very being—his capital and stock-in-trade. There are no very well-marked physical appearances characteristic of this stage of hunger, for noticeable emaciation has not yet set in. A vulpine gleam there may be in the feverish eye, but beyond that and the generally dejected and morose expression of the features there is hardly anything very peculiar in the visage of the starving man.

On the march, however, one can almost always tell when this stage of hunger has appeared, by the sudden collapse of animal spirits to which the most good-natured of those suffering are subject, and by the sombre cloud of dull, desperate sulkiness that is flung like a pall over each man's heart, in virtue whereof attached comrades begin to eye each other savagely, as if they were deadly enemies. Then it comes to pass, when the moment of keenest agony is reached, that the starving man begins to eye his companion with the wolf-glare of a beast of prey. His pangs become paroxysmal. During their greatest intensity there springs up within him a fierce impulse to slay his neighbour, that he may feed on his flesh and slake his thirst with his blood. This terrible prompting to cannibalism, it may be noted, is, however, rare, save in cases of famine from shipwreck. Although it is customary to regard it as a common feature of starvation, and to make thrilling statements of the frequency with which even mothers will, under the goad of hunger, kill and eat their children; and though startling assertions to this effect have been made by historians of great sieges; yet it ought to be said that as a general rule well-authenticated cases of cannibalism amongst civilised people will be found to occur only at sea. They are very rarely found on land. And what is more curious still, whenever famished shipwrecked men set foot on shore, no matter how desolate and barren may be their rock of refuge, they seem as if by magic at once to banish from their minds the very idea of anthropophagy or man-eating, and that, too, though they might have been resignedly contemplating it as an imperative necessity a few hours before. In the case of Ensign Prentics, of the 84th Regiment, and his companions, who were wrecked on the barren island of Cape Breton in 1780, the difference between famine on shore and on sea is curiously exemplified. Prenties records that they were able to endure the most fearful pangs of hunger without ever so much as a thought of resorting to cannibalism for relief, so long, however, and only so long as they kept on land. But when they took to their boats—and it was not once merely that they experienced this—in order to escape from their rock-bound prison, though they were not a whit worse off for food than they were on land, yet the moment they put out to sea, with one accord they began to think of killing and eating one of their number. On the other hand, when they found their attempt to escape futile, and put back to shore, whenever they landed, the horrid idea of

cannibalism seemed to vanish. The old Hellenic myth tells us that Antæus, fighting with Hercules, as often as he was beaten to the ground was filled with new strength through contact with his mother Earth. To the fanciful it might seem as if contact with *terra firma* had a not very dissimilar moral influence on the famishing mariner, filling him with fresh vigour of will to resist unnatural appetites bred of hunger-pangs. But perhaps the more rational explanation may be found in the hypothesis that whilst starving men are voyaging about in an open boat, exposure to the keen sea-air probably sharpens their appetite for food, and so materially increases the agony of starvation that their natural loathing for human flesh is overcome.

After this period in the progress of starvation is passed, even competent medical writers used to assure us, the mind of the victim gave way under the torture of bodily sensation and the anguish of frenzied thoughts. A careful study of cases of starvation in which faithful record of the sensations experienced has been kept, leads us to very different conclusions. There is no "anguish" felt in the ultimate stages of starvation. After or about the fifth or sixth day, the pain of hunger gradually ceases to be felt, and the sharp edge of craving becomes dulled. Emaciation sets in, the eyes sink in the sockets, their pupils are dilated, and a ghastly glare is emitted from between their unclosed and motionless lids. The skin is wrinkled, and of a dirty-yellowish hue—indicated failure of the circulation of the blood in the capillaries, or minute, hairlike blood-vessels of the skin. The cheeks fall close to the jaws, the lips lie thin and tremulous over bloodless gums, and the quaking limbs are scarcely capable of voluntary motion. After this, feeling becomes partially benumbed, the senses as messengers of intelligence play the victim false. There is no pain, and the mind lapses into a state of incoherence and sleepless delirium. Such are the more salient phenomena of starvation ere it culminates in the last torpor of death.

Now if this description be carefully scanned, two facts must stand forth as very noteworthy. The starving man, it will be observed, begins to lose flesh before he loses brain-power. In spite of the enfeebling action of inanition, he is tortured by sleeplessness; indeed, so far from his brain becoming torpid, it develops an abnormal amount of activity and excitability, as evidenced by delirious raving. In short, ere the painless stage of hunger is reached, bodily emaciation has preceded derangement of the nervous system, and the brain, so far from ceasing to work, is in a state of abnormally exalted activity. Now this is somewhat singular. We should expect that—as the nervous system is the most delicate and complex, in point of minute structure, in the body, it would suffer first from emaciation, or the suspension of nutrition—that it would show signs of wasting before the rest of the frame began to waste. Yet that the contrary is the case may be proved otherwise than by merely noting that emaciation precedes nervous derangement in the starving man. If, for example, any animal be starved to death—and the cruel experiment has been made more than once—it will be found that whilst it has lost only two per cent. of the nerve and brain-tissue, more than forty times as much of its fat, and more than twenty times as much of its muscle or flesh, have gone. Indeed, though the fat is the tissue that breaks up soonest, that portion of it in the brain-substance is scarcely affected by starvation. We may thus arrive at a very simple explanation of what is otherwise strange—the curious sleeplessness and abnormal mental activity produced by excessive hunger. They are due to the comparative immunity from waste which the brain and nerve-tissue enjoy during starvation. This structure has no longer to supply nervous energy for carrying on nutritive functions, which are suspended by inanition. Relieved from this task, its liberated power expends itself—partially, at least—in the unnatural exaltation of the nerve-centres, in other words, of brain-action, which results in sleepless delirium. Moreover, the very relief from the duty of supplying nerve-force to the organs of nutrition, slackens the speed, if it does not altogether stop it, at which the nerve-tissues would otherwise, in the ordinary course, wear and waste.

One of the most remarkable effects of hunger is that which it has on the blood. In the blood-liquor there are floating large numbers of minute discs, coloured and colourless, which act as carriers of nutrition to the tissues. There are also held in solution and suspension certain substances, the products of disintegrated structures, which are always being removed. Now, hunger diminishes the quantity of blood-discs, but increases the quantity of waste products in the blood. Clearly, this double action, diminishing the nutritive element of the blood, and increasing the products of disintegration in it, cannot go on for ever. It must have a limit. This leads us to ask, When does starvation pass the boundary-line of life? The point at which starvation becomes fatal is a shifting one. Much depends

on the rate at which the tissues of the body break down. That rate, again, must vary in proportion with the stillness or activity of the starved body. Every movement must be made at the cost of a certain amount of destruction of substance; and if the body could be kept absolutely still, abstinence from food might be prolonged for an enormous length of time. The miraculous power of fasting ascribed to hysterical devotees is thus explicable. Where these people are not sheer impostors, it is usually found that the fasting person is bedridden —is kept lying in a state of profound rest, not even being able to speak. It will be also found that the waste of tissue in such a case is reduced to the quantity broken down in those chemical actions which generate animal heat, and to that wasted by the scarcely perceptible pulsations of the heart, and the minimised respiration whereby, no matter to how slight an extent, the blood exchanges oxygen from the air for carbonic acid, the product of worn-out tissue. That this minimised waste goes on and must go on as long as the fasting person retains a spark of life, is a self-evident fact, just as much as it is an obvious truth that if we keep a machine going—no matter how feebly —it must in some degree wear away, no matter how imperceptibly. We can therefore infer that the infinitesimal waste of tissue in a "fasting" *religieuse* is replaced by an infinitesimal amount of nutriment administered at intervals, either openly or surreptitiously, or that if this source of supply be carefully cut off, as was done in the case of the famous Welsh fasting girl, death results whenever the cumulative amount of the waste reaches a certain point. Now how far can the body waste away without dying? Whenever the body of a starving man or animal loses two-fifths of its substance, it loses life also. No amount of incantation or modern miracle-mongering will enable the fasting devotee to live after he loses forty per cent. of his weight. Of course the semblance of a miracle may be manifested, by prolonging the time during which this waste is endured. Though a week's starvation will kill a man, yet it will take nearly half a year (161 days) to starve a reptile to death. If the human being be reduced to that state of absolute quiescence which most closely simulates the sluggish vitality of a frog, a miraculous amount of very respectable fasting may be spread over half a year. The administration of liquids—even of pure water— will more than double the length of a starving man's life. But it matters not whether the abstinence from food be complete, or partial, whether it be tempered with the administration of liquids, or not; there is no escaping this inevitable doom—that whenever, be it sooner or later, hunger robs the living body of two-fifths of its substance, it robs it of life also.

Passing by many interesting points connected with abstinence from food—such, for instance, as hibernation—we hasten to say a word on what is rather an obscure question. What is the cause of the sensation of hunger? The popular instinct, of course, answers, Want of food; and no doubt that is the explanation that lies nearest the investigator. Food has been called the fuel of life—though it would be more correct to say that the fuel of life is that whereof food is the raw material—to wit, the tissues of the body themselves. But, without over-subtle refining, it is very apparent that if we withhold that which builds up its fuel, the fire of life will soon be quenched. Hunger is the first warning signal given to let us know that the body's store of fuel needs replenishing; and in this sense it may be said that the want of food causes the pain of hunger. But if want of food causes the hunger-pang, it is strange that the administration of substances that are not food will dispel it. For example, chewing or smoking tobacco, eating lumps of clay, as do some South American Indians and other tribes, will remove the painful sensation of hunger, quite as effectually—for the time, at least —as a hearty meal.

Probably this fact led observers to seek in the physical effects of mere emptiness of the stomach a satisfactory explanation of the pain of hunger. When there was no food in the stomach for the acrid gastric juice to act on, that secretion was, according to some, poured out on the coats of the organ itself, and by corroding them it was thought to produce the pain of hunger. The only difficulty about this simple theory was, that when the stomach has no food in it, the gastric juice, as a matter of fact, is not poured out at all. Food must be present, acting as a stimulus, ere the flow of the secretion be provoked. But it was said by other physiologists that though the gastric juice was not poured out when the stomach was empty, yet it was accumulated in the little secreting-pits or follicles that dot the walls of the cavity. There being no food to summon it forth, it kept on accumulating in these minute pits till it swelled them out to an extent that made them pinch the ultimate ramifications of the gastric nerves, thus causing acute pain. This theory would be very plausible if the gastric pits were covered with water-tight lids which were shut

when the stomach was empty, but which flew open when it was filled with food; this, however, is not the case. The mouths of the gastric pits or follicles are perfectly open. Whenever gastric juice accumulates in them, there is nothing whatever to prevent it from running out. Like all fluids, it must move in the direction of the least resistance. It would naturally rather run out at the open orifices of the secreting-pits in which it was formed, than remain in to distend the walls of these pits in a futile attempt to escape at the wrong or closed end of them. Perhaps the oddest belief about the cause of hunger-pangs is one which is to this day the most popular. According to this view, when the stomach is empty its walls fall together, and their surfaces, grinding over each other, produce extreme pain. A very simple experiment will suffice to dispose of this theory. If a starving man be taken, and liquid food, say milk, be injected into his veins, he ceases to feel the pain of hunger. Yet nothing has been put into his stomach. That cavity is as empty after the experiment as it was before it. Its surfaces must be "grinding over each other" as grimly as ever; yet the pain this process was supposed to cause has vanished.

No explanation yet examined is satisfactory, and the facts elicited are rather conflicting. Swallowing other things than food will dispel the pain of hunger. That pain may also be made to disappear without swallowing anything at all. The local application of certain substances to the stomach, and the introduction of fluid food into the veins or the general blood-circuit, have seemingly the same remedial effect. It will not do to fly to the common refuge of the perplexed biologist, and say the mystery is due to some derangement of "the nervous system." Hunger, even when it develops into starvation, has, as we have seen, hardly any marked effect on nerve-tissue. Besides, if the pneumo-gastric nerves which supply the stomach be cut—that is, if the nervous system of the stomach be practically eliminated from the field altogether, it is found that the sensation of hunger continues just as if nothing had happened. By a process of exhaustion, we are driven to conclude that as the seat of hunger is undoubtedly the stomach, the cause of the hunger-pain must be sought for in some peculiar modification suffered by the tissue of the organ itself. We are also forced to conclude that this modification must be so peculiar that it can be corrected by direct local and indirect general applications—by a bolus of clay as well as by the injection of milk into the veins. Now, the only modification apparent in a hungry stomach which could by any chance satisfy these conditions, is its extreme bloodlessness. Whatever hurries the circulation of blood in a fasting stomach, it is noticed, relieves the pain of hunger. The direct application of a bolus to the stomach, acting as a mechanical stimulant, may have this effect. On the other hand, the injection of fluid food into the veins may correct that general alteration which, as we have seen, fasting produces in the blood, and which, carrying a feeble and depreciated supply of nutrient fluid to the tissue of the stomach, produces in it that specific modification which manifests itself in the local sensations of hunger. The theory of hunger may be thus formulated. Fasting produces a general change in the organism as a whole. This again brings about a specific change in a particular part of the organism—the stomach—of which the pain of hunger is the local symptom. Direct applications, such as a bolus of food, or even of clay, temporarily relieve this local feeling of pain, by neutralising the specific local changes to which that feeling owes its origin. Indirect applications, again, such as the injection of milk into the blood, correct the general alteration of the system produced by want of food. By doing so, they correct those local gastric changes produced by the general effect of fasting in the system—changes which render the local manifestations of hunger possible.

## A FALLEN LEAF.

BY ROBERT BROWN, F.L.S., AUTHOR OF "A MANUAL OF BOTANY," ETC.

SUMMER is the harvest-time of the botanist; but autumn is to him not without its charms. It is the season of seeds, and fruits, and late-flowering plants—last harbingers of the floral crop that Nature reaps before the arrival of the winter, which in our northern climate reduces active life to a minimum. Above all, the autumnal months are the season of the falling leaf. Forests containing a variety of broad-leaved trees are at this season almost more attractive than during the heyday of midsummer. In June,

the unending vistas of green are fresh, but in some degree monotonous. But in September and October, the green leaves not yet passing into the "sere and yellow," are relieved by the endless colours—yellow, red, brown, and motley—which the dying foliage takes; *the woods seem to have changed their dress. Even in the winter the stripped trees are not without a certain weird, ghostly beauty all their own.* "*Foot bound, uplooking at a lovely tree, beneath a frosty morn,*" *at this season, the botanist* can examine the outline of the tree then revealed to him by the absence of its leafy dress, and compare—if he is gifted with the "scientific use of the imagination"—the veining of the skeleton leaves tossed about by the wind among its feet, with the branching of the trunk before him. Let us, therefore, before materials for our little study get scarce, try and learn something from an examination of the leaves around us, or whirled about by gusty breezes which sweep through the woods and tree-bordered parks of the great city wherein we write this. Here are three leaves (Fig. 1)—one (A) bright, fresh, and green, whose duration of life is not yet past; we pull it off the black poplar-tree on the lawn. A second (B), getting yellowish and dry, has fallen of its own accord, its life having ended; it is dead. A third (C) we can easily find on the little bank which early in autumn has accumulated in some by-corner near at hand. It is a leaf of the same tree, but the flesh has long ago rotted off its bones; and what was once green and living is now seen in the form of a mere skeleton outline, bleached white, though still preserving its original shape. The green leaf is more or less rounded in outline, as all leaves are, rather longer than broad, and pointed at the end, giving it roughly the form *of a triangle. The blade of the leaf rests on a leaf-stalk, which seems prolonged through the mass of soft green substance which plays the part of flesh to it, in the form of a central back-bone, from which are given off on either side* ribs, which again branch out into a network of minor sub-divisions. The whole is covered over with a thin skin, which with care can be peeled off in little bits. Last of all, we see that the under surface of the leaf is, like the under-surface of nearly all the leaves around us—no matter from what species they are derived—lighter coloured than the side which looks towards the sky, and is also not so glistening or smooth as that is.

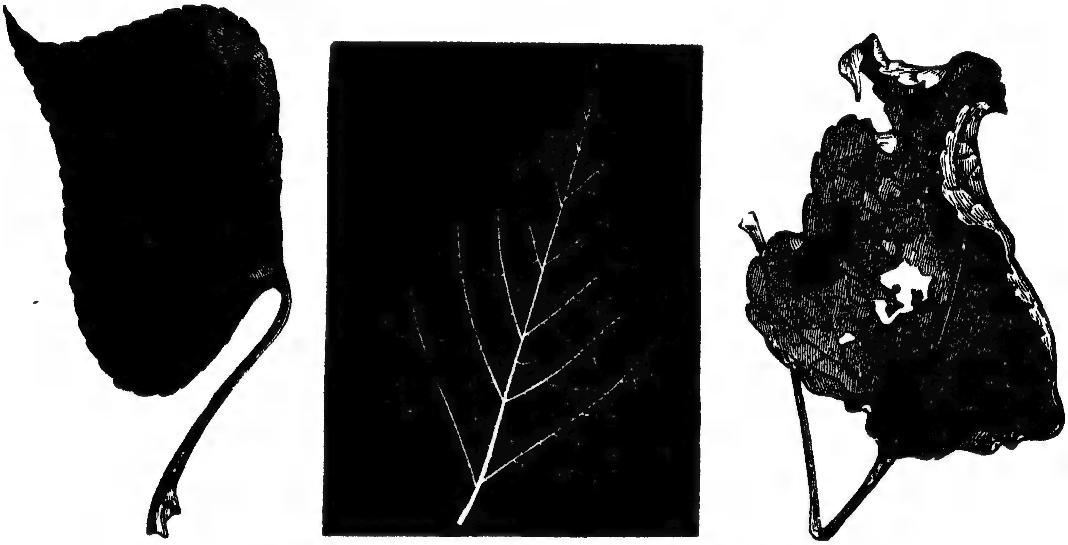


Fig 1.—Three Stages in the History of a Black Poplar-Leaf.

(A) The Fresh Leaf. (C) The Skeleton Leaf. (B) The Withered Leaf.

We have now seen nearly all that the naked eye has the power of revealing to us; but, as nearly everybody has one of those artificial eyes or sets of eyes called microscopes, now to be bought so cheaply, we may for a brief period adjourn our examination from the garden seat to the study window. With a needle we can detach from the under-surface of the leaf a tiny bit of the skin or covering of the leaf. Press it gently on a slip of glass, and put it under the microscope. Here is what is seen (Fig. 2). We perceive that the whole surface is studded over with little openings, each like the opening in

the centre of the letter O. These are the pores or mouths of the leaf-skin. They are found in greater or less abundance on all green portions of the plant covered with this skin, and even here and there on the flower-leaves, but in infinitely greater abundance on the leaves, and especially their under-surfaces, than anywhere else on the plant. Beneath,

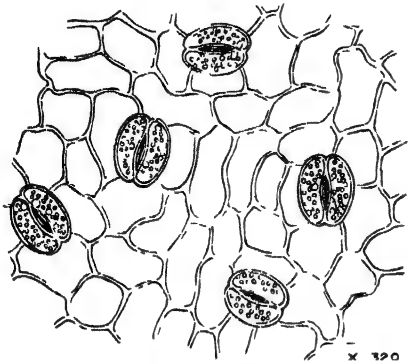


Fig. 2.—A Piece of the Leaf-Skin showing the Pores or Mouths (*Stomata*) on it.

these pores open into little chambers in the soft green substance of the leaf, and generally are in communication with all the air-passages which, as we shall presently see, interlace through the substance mentioned (Fig. 3). The number of these mouths found on leaves varies from a dozen or two up to about 160,000 on a square inch. On the leaf of a lilac, 708,750 have been counted; while an entire leaf of the lime, or linden-tree, has 1,053,000. It is hardly worth taking the trouble to count them here. To examine the substance of the leaf is not so easy. But if we manage to cut a thin slice across the blade, we shall see under the microscope something like what we have portrayed in the accompanying cut (Fig. 3). It will be observed that between the upper and under skins of the leaf is a green substance, which is made up of roundish bladders—the "cells" of the botanist—each cell containing in its interior a green substance floating about in a watery or glairy fluid. This is known as leaf-green, or—if you wish a longer name—chlorophyll. This leaf-green, seen shining through the transparent walls of the bladders in which it is contained, and the skin of the plant, give the green appearance to leaves; for the skin itself, though also composed of these bladders, flattened out and arranged side by side like the bricks in a wall, contains no green matter—and, indeed, nothing but air. Ramifying through the midst of this bladder structure—and indeed supporting it, and acting as a framework, every little vacant space in which it fills up—is a thin network formed by the branching of the leaf stalk through the blade. This framework we shall have occasion, by-and-by, to again speak of, when we examine our skeleton leaf. Meantime, this cursory examination may suffice. We may, however, add that the leaf-stalk and its branched and netted prolongation through the blade is composed of bundles of tubes or vessels placed side by side, and bound together. These tubes carry up the nourishment from the stem to the leaves; hence,

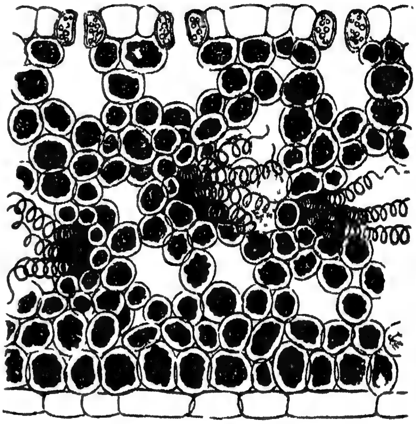


Fig 3.—The Leaf cut across.

from a fanciful idea of their resemblance to the blood-vessels of animals, they have been called the *veins*, and we still speak familiarly of their branching throughout the leaf as the *veining* of that organ.

We have thus concluded a cursory examination of the leaf's anatomy; and cursory it must be, considering that volumes have been written regarding what we have been forced to dismiss in a few lines. It is sufficient, however, for our purpose. If, during the time this dissection has been going on, we had placed a poplar-leaf freshly taken from the tree into a wide-mouthed glass bottle, covered it with water, and placed it exposed to the full glare of the sun, we should have seen bubbles of air arising from it. If, on the contrary, the bottle is exposed to darkness, we shall also see bubbles given off. But, if we are chemist enough to learn this for ourselves, we shall find that the daylight and the darkness bubbles are composed of different gases. If not, then we must take the statement on the word of others, who assure us that in the first case they are composed of oxygen, in the second of carbonic acid gas. Now, both of these gases enter into the composition of the air, the first to the extent of about one-fifth of its whole mass, the other to only a small fraction. The oxygen is to animals the life-giving gas; carbonic acid is breathed out by

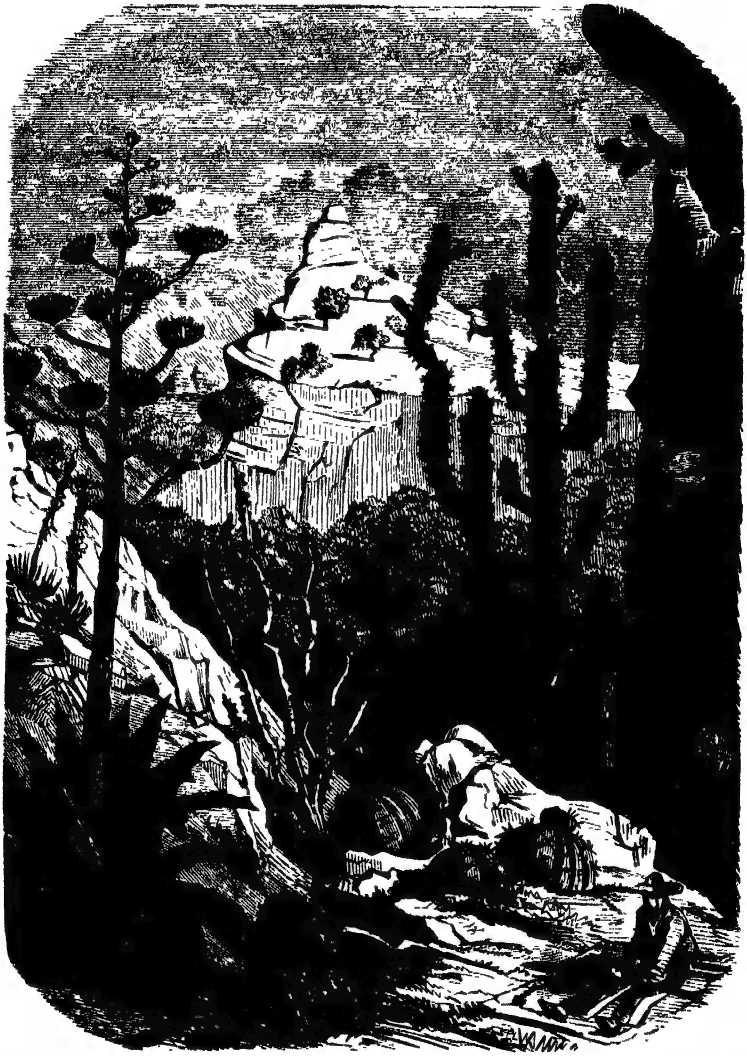
them, and is fatal to their life. The oxygen will cause the spark in a bit of wood to burst into a blaze: if the same bit of half-ignited wood is put into a vessel containing carbonic-acid gas, it will be extinguished. The latter gas is vomited forth in great quantities from volcanoes, is breathed out by animals, given off by the rotting of dead plants and animals, &c. Small as is the percentage of carbonic acid in the atmosphere—forming, as it does, only one-millionth part of it—there must be in the air 138,616,075,892 tons of carbon, or that component part of carbonic-acid gas which, in the solid form of charcoal, is familiar to us. It is found that plants while exposed to sunlight take this carbonic-acid gas from the air, by aid of the leaves and other green parts. Now, the chemical composition of this gas is one part of carbon, and two parts of oxygen ($CO_2$ is the chemical "formula"). Once absorbed into the body of the leaf, a change takes place there through the aid of the sunlight and leaf-green in the cells. In other words, the carbonic-acid gas is decomposed into its original elements. The carbon is retained by the leaf, in order, as we shall see in another paper, to help to build up the body of the plant, while the oxygen is sent out into the air. It was this exhaled oxygen which we saw ascending in bubbles through the water, and which if collected in a corked funnel placed over the mouth of the bottle, would have revivified a spark, or even caused a blown-out taper to burst into flame. In the darkness, an experiment conducted in exactly the same manner shows that a directly contrary action takes place. The plant, instead of giving out oxygen to the air, absorbs it and gives out carbonic-acid gas, but in smaller quantities. Where this carbonic acid comes from is not very clear. It is perhaps derived from the combination of the oxygen with the carbon of the plant; or it is perhaps only the carbonic acid drawn from the soil escaping from the sap undecomposed, during the absence of sunlight. Now it may be asked, if this is so—and without going into a discussion of moot questions, the reader may take the writer's word for it, that it is so—is it not unhealthy to keep plants in bedrooms, or in rooms where people live? Do they not contaminate the air at night, by giving out this poisonous gas, identical with the fumes from burning charcoal, or those which kill the dogs in the pestilent Neapolitan Grotta del Cane? Of course, theoretically they do; but, practically, so little is evolved by a window-sill full of plants, that the reader may sleep even in a conservatory without serious danger from suffocation. In a greenhouse containing 6,000 plants, it was found that after being closed for twelve hours, the carbonic-acid gas only amounted to 1·39 in 10,000 parts. This "inhalation" and "exhalation" goes on chiefly through these mouths or pores which we have described (Fig. 2); and in water-plants exactly the same interchange of gases is hourly in progress. Only, in the latter case, the air is dissolved in the water, and the breathing does not go on through the little mouths—these being wanting on the surface of aquatic plants exposed to water—but through the skin generally. The oxygen absorbed by plants goes through the mouths into the little chamber beneath, and then, by means of little air-passages or canals between the bladder-substance, circulates all through the body of the plant. Plants are thus the scavengers of the atmosphere, removing the carbonic acid exhaled by putrefying matter, volcanoes, manufactories, &c., and giving out, instead of this gas, so poisonous to animal life, oxygen. Water-plants perform the same office—viz., "oxygenating;" hence we grow the water plants in an aquarium. It thus appears that leaves are the lungs of plants, and that the little bladders serve much the same purpose as the "air-cells" of the lungs of the higher animals. But lower down in the scale of life, we find one organ having to perform many functions, just as in a low state of civilisation many duties are performed by one individual.

If we examine some plants, particularly in the morning, we will frequently see drops of moisture standing at the points of the leaves, or accumulated in the pits between the teeth, should the leaves have these divisions on their edges. In some cases this is merely the dew, or the insensible perspiration of the leaf condensed. But in most cases it is a true perspiration, in drops. Occasionally this fluid will have an odour resembling that of the plant which gives it off, just as the perspiration of animals will often bear the same smell as that of the animal itself. In some plants, like the so-called Ethiopian lily, considerable quantities of water exude from the points of the leaves; frequently even on dry, dewless nights, when there is no moisture in the air, drops of water may be seen hanging from the tips of the branchlets of the common horse-tail, or *Equisetum umbrosum* of botanists. All plants, however, give off moisture from their leaves, even though this is invisible to the eye, just as our skin is always perspiring, though the sweat may not stand in drops. This can be seen if a plant is grown under a glass shade, in such a manner that no evaporation can be given off by the earth or water in which it

is grown. Nevertheless, in a few hours the inside of the glass will be dimmed by the moisture given off by the leaves, which has condensed on it. Calculations have been made as to the amount of water thus perspired by plants. A sunflower, only 3½ feet high, with 5,616 square inches of surface exposed to the air, gives off every twelve hours twenty to thirty ounces avoirdupois of water in this form—which is more than a man does. Most of the common agricultural plants, such as wheat, beans, peas, and clover, exhale during the five months of growth more than two hundred times their dry weight of water. The Cornelian cherry is still more remarkable. In the course of twenty-four hours it exhales water equal in weight to twice that of the whole shrub. Naturally, the degree of light, warmth, and dryness of the air affects the amount of fluid given off, as well as the age and texture of the leaf. However, a calculation of the amount of fluid perspired by an acre of cabbages may be curious. If the cabbages are planted in rows 18 inches apart and 18 inches from each other, it is estimated that in the course of twelve hours no less than 10 tons 4 cwt. 3 quarters and 11 lb. weight of water will have been insensibly perspired by their fleshy leaves. We now see why a plant gets "wilted" on a hot day if it is not watered. More water is given off by the leaves on a hot day than is naturally sucked up out of the soil by the roots. Hence the gardener has to supply the deficiency by "watering," if he wishes the plant to live. This perspiration of the leaves goes on chiefly by means of the minute little mouths which we have mentioned as being scattered over the skin of the leaves. These little mouths open and close so as to regulate the amount of moisture to be given off. If the day is very hot or the plant is absorbing much moisture from the soil, then the mouths close, and give off perspiration very niggardly, and *vice versâ*. A good deal of moisture is also given off through the thin skin of the leaves. Accordingly, plants which grow in deserts (Fig. 4) have their skin much thicker than those inhabiting moist countries, so that the life-blood of the plant may be economised to the utmost extent. For the same reason, apparently, the former are also much more fleshy. The different species of cactus are examples. If leaves are smeared with oil, and in this manner perspiration prevented, the plant will die; just as, in a similar case, a human being would if the pores of the skin were all closed. All of these facts cannot be observed on the leaf under examination. But the chief points we have discussed can be seen by a very casual observation of the leaves of the plants in any field, garden, or shrubbery. We have thus seen that the leaves also perform for the plant the part of the skin in the higher animals, in addition to that of the lungs. This "transpiration" of moisture through the leaves, also explains how plants can be transported from country to country, or kept in a room, in the closed glazed boxes called Wardian cases. A Wardian case is closed on every side, and does not require to be opened, on the passage from one country to another, for the plants in it to be watered, a small amount of moisture sufficing, on account of the water sweated by the leaves being used over again and again, the only water consumed being that absorbed into the substance of the plant. A Wardian case thus demonstrates the economy of vegetable life, on a small scale.

The leaves are, however, even more to the plant than lungs and skin, as a very little observation will suffice to show. Pull off a piece of the bark of a tree in mid-winter, and the task will be found rather difficult, owing to the absence of any appreciable amount of moisture between the wood and inner bark. Do the same in the spring, and it will be found that the bark comes off with the greatest ease, owing to the amount of moisture in the place where only a few weeks before was nothing but dryness. Try again the same operation in autumn or late summer, and it will be seen that a slimy, sticky substance intervenes between the bark and the wood. The moisture of early spring was the sap ascending through the wood to nourish the plant, and the sticky substance we now find is the same sap descending, and in its course forming new layers of wood and bark. The nature of this sap, and the function it performs in the plant, will be the subject of another paper. Meantime, the ascent of the sap is not a statement that need be taken on any one's credit—the reader can see it for himself; and if he has ever lived in the American backwoods, he must be familiar with it, in the form of the sweet sap which the Indians and settlers collect in spring from the sugar-maple tree, for the purpose of boiling down to make maple sugar (Fig. 5). Its descent in the autumn is proved by tying a cord around a tree. The sap being thus prevented from descending, accumulates above the ligature, and being transformed into wood and bark, forms a large bulge or swelling in the branch or trunk of the tree. When the sap ascends in spring it is a crude, sweetish liquid. When it descends in the autumn it is a thick and concentrated liquid,

containing starch, sugar, and other substances, in addition to those which it originally contained. Some of these it has picked up in its travels up the stem; but many of its changes have taken place in the leaf. Into the leaves the sap has gone, passing from one little bladder to another; there, we have seen, it has been exposed to the air, in these little bladders or cells. It has been subjected to the action of certain gases, and has become thickened by the sweating or evaporation which we have described. Having thus been, as it were, digested, it leaves the leaf by the only outlet by which it could either come or go—viz., by the bundle of vessels which collectively form the leaf-stalk. The leaves also, it would appear, aid in causing the sap to ascend. The roots may pump it out of the soil, but the leaves draw it up, in much the same manner as the flame of a lamp acts as a stimulus to the oil to ascend in the wick. The sap never ascends without the leaves being expanded. This may be easily demonstrated. Observe two shrubs growing outside a conservatory. In both the leaves are in bud; and, as an incision in the stem will show, in neither has the sap begun to ascend. By putting the budding branches of one inside the warm conservatory, and so causing the leaves to prematurely expand, then in this shrub the sap will begin to ascend; while in the



. 4.—Vegetation (Aloes, Cacti, etc.), of the Mexican Uplands, or Tierras Frias.

one outside, growing in the same soil, but, owing to its being exposed to a different atmosphere, still in bud, the sap has not yet taken the initiatory steps in its progress heavenward. A leaf thus serves a third and very important object in the economy of the plant; it constitutes the stomach of the plant. In fact, a plant may be said to consist of a series of individuals called leaves, united, as some of the lower animals—plant-like animals, the higher animals is sent through the body. The leaf-stalk also bears out the analogy; for just as the aorta in very old people becomes bony, and can no longer perform its all-important functions, so in like manner the leaf-stalk in leaves which have finished their course becomes clogged with mineral matter.

This brings us to examine the second leaf in the specimens we are studying—viz., the one which, yellow and dry, has fallen of its own accord. It is

Fig 5—Indians gathering Maple-Sap in the Canadian Backwoods

called zoophytes—are, on a common stem, each individual containing many stomachs—the bladders of the leaf-substance.

Finally, it is not carrying the analogy of plant and animal too far if we also claim for the leaves the functions of hearts. They are lungs, because they are the breathing-organs of the plant. They serve as skin, because through them the plant perspires. They are stomachs, because within their "cells" the nutritive fluid gets fitted for building up the plant. But this nutritive fluid is also, after it leaves the leaf-stomach, the blood of the vegetable. Hence the leaf is a heart which despatches it on its body-building errand, and of course, if this simile is admitted, then the leaf-stalk is the representation of the aorta or great artery through which the blood from the heart of

yellowish—why is this? Here, again, we must call in the chemist's aid, and he will tell us that the colour is due to a chemical transformation which has been going on in the leaf-green or "chlorophyll." The same is true of the red, brown, and all other coloured leaves with which the ground is so plentifully strewn around us. The chlorophyll is there, as it was in the green leaf which we have been examining; but it has no longer the same composition. It is changed in its composition in that mysterious series of little laboratories which are contained within the two walls of the leaf. Some will even declare that the various autumnal colours of leaves are due to the production of new substances in the leaf. The chemist has furnished us with a long—a very long—list of these substances, with

names strange to all but himself. However, we need not trouble the reader with them, more especially as the catalogue would in no possible way either instruct or amuse him. But we are not done with the fallen leaf. It is dry: that naturally follows. It has ceased to receive any sap, and has given off all it stored in its bladder-stomachs, and the bladders themselves, having now no longer any work to do, have shrivelled up for ever. But the leaf has not been torn off: it has fallen, in the fulness of time. Examine the end of the leaf-stalk; it is not torn, nor are the vessels composing it hanging loose in any way (Fig. 6). They are neatly cut off, smooth, and unopen, as may be seen if even a magnifying-glass is applied to the end of the stalk. The same is true of the place from which it has fallen. There within the scars can be seen numbers of little "dots" showing where the different bundles of vessels entered the stem. Here let the reader at once understand that, except in familiar parlance, there is no such thing as evergreen trees or shrubs. In the plants so called, the leaves do not remain all the year round. In reality, only the leaves of last season remain attached to the stem and branches until the development of those of the next spring, when they fall; the result being that the is covered with a continuous mass of green leaves, which in popular belief are the same as it was clothed with in the former season. Neither is it true that pine, and other trees of that order, do not shed their leaves. In some species, however, the leaves will remain attached for from two to even ten and twelve years; but fall they do in the end, as an examination of the ground in a forest will abundantly testify. In tropical countries, plants often lose their leaves during the dry season, and develop new ones during the rainy one. All leaves—those of grasses and similar plants excepted—thus fall.

How, then, is this important physical and physiological act accomplished? Simple as it seems, it is not easy to observe it, and endless have been the theories to account for it. It seems to the writer—and the reader can judge for himself—that the way in which it is accomplished by nature is just that way in which the surgeon divides a vessel or bundles of vessels when he wishes the operation to be performed gradually, and without causing the open ends of the vessels to bleed. If he cut them across, then their open mouths would allow the blood to escape. Accordingly, he ties a ligature or thread around the vessels. Gradually a contraction forms, and little by little the vessels are divided, the ends closing at the same time, and the severance from the body is accomplished without loss of blood. Now this is just the way nature takes to sever the leaf from the branch or stem. Almost as soon as the leaf is developed, the process which is to sever it from the stem commences. A contraction forms near the point where the leaf-stalk is attached to the branch. Slowly it deepens and deepens, until so slight is the joint which connects it with the parent plant, that a slight twist, or even the simple weight of the blade, serves to detach it. The leaves of some

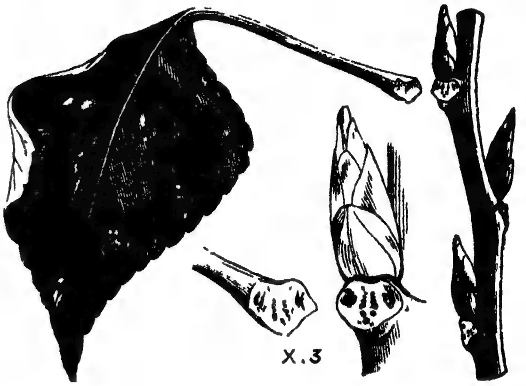



Fig. 6.—The Fall of the Leaf; showing the Leaf dropping from the Branch, the next Year's Leaf-Bud formed; the Scar, with the divided Bundles of Fibres, and the End of the Leaf-Stalk, magnified three times (× 3), showing the corresponding Bundles of Fibres.

trees, like the oak, for instance, though they die and become withered in the autumn, frequently remain attached until next spring, when the enlargement of the stem detaches them. It is thus apparent that the death of the leaf and the fall of it are not the same, and that the one does not follow the other. It appears that the death of the leaf is owing to the vessels of the leaf-stalk getting choked up with the earthy matters left behind by the evaporation of the water which held them in solution, until, no more sap being able to enter the leaf, its functions cease, and it dies. Accordingly, if we care to make the experiment, we shall find that in the autumn leaves contain much more mineral matter than in the spring, and that their vitality is more or less active in proportion. Thus, when the leaf falls, it returns to the soil a certain amount of the mineral ingredients which the root extracted from it in the course of the growing-season. Hence also one of the reasons why leaves form a valuable manure.

We have now examined the life, death, and fall of the leaf. Let us direct our attention briefly to the skeleton one before us. What the skeleton is we

have seen. If we could fancy the bones in an animal acting at once as skeleton and blood-vessels, then they would conjointly be something of the same nature as the skeletons of leaves. The only other point we shall direct the reader's attention to is the curious relation which the shape of many leaves bears to the shape of the trees which bore them. In fact, a tree stripped of its leaves often looks like a huge outline of the skeleton leaf lying under its shade. The angles at which the branches are given off from the stem also bear a close relation to the angle at which the side-ribs in the leaf are given off from the mid-rib. This is seen in the poplar-leaf before us. The shape of the leaf is really the shape of the tree, which is again determined by the angle at which the branches are given off from the trunk. The curve of the branches and the curve of the ribs in the leaf also correspond. In some leaves there is no leaf-stalk. In such a case we find—as in the beech—that the trunk is naturally branched from the ground. On the other hand, a leaf with a leaf-stalk—as in the case before us—implies that the species of tree on which it grows has naturally a bare trunk. In the poplar and beech also may be observed a correspondence between the disposition and distribution of the branches, and the disposition and distribution of the leaf-veins. This can be readily seen in the annexed figures of skeleton leaves (Fig. 7).

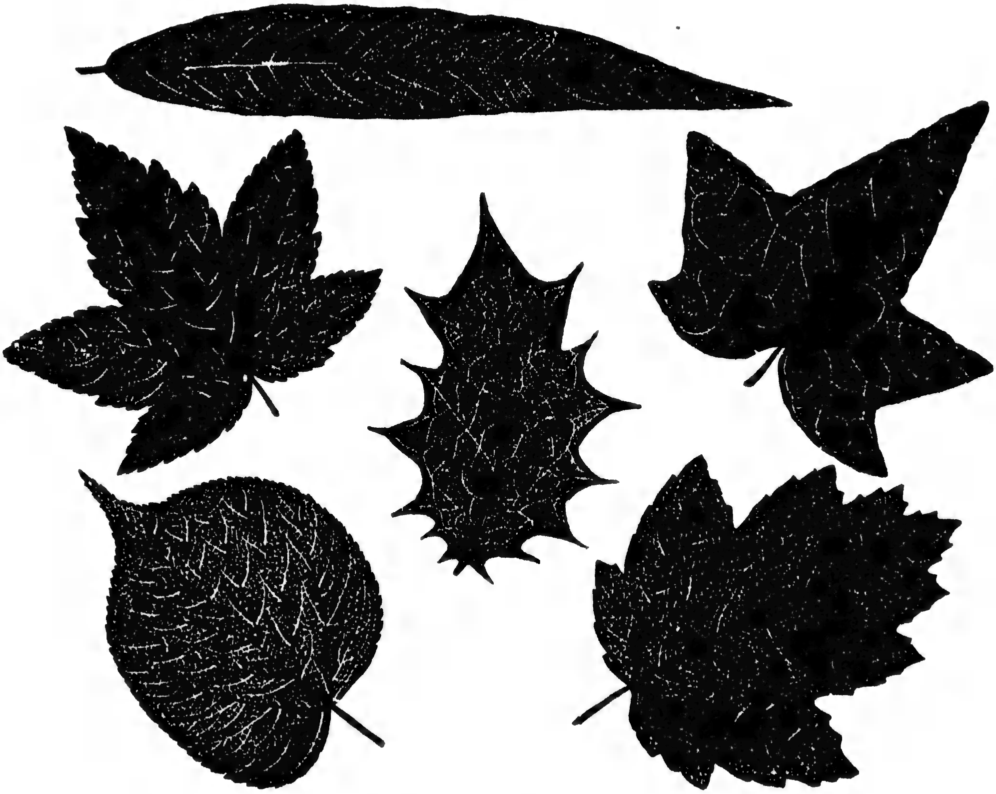


Fig. 7.—Skeleton Leaves, showing the Relation between Branching and Veining.

We have now finished our study of a fallen leaf. The reader will have seen that there is enough to observe in it; and yet we have not touched on many subjects of interest. We might have spoken of the beautiful hairs and scales which are frequently found on leaves of plants like the sundew, pitcher-plant, and others, which not only catch flies, but absolutely eat them, and prosper on the diet. Neither have we allowed ourselves space to describe the beautiful regularity with which leaves are attached to the branches; the study of these mathematics of plants forming a fitting subject for another lesson. Last of all, we need scarcely inform those in the

slightest degree acquainted with vegetable physiology, that on all the points we have discussed there *are many and rival opinions*. Hence we have been forced to be eclectic, but believe that we have been, so far as our space will admit, accurate in describing the anatomy and history of a fallen leaf.

# *ICE, WATER, AND STEAM.*

By J. E. H. Gordon, B.A., M.S.T.E.

EVERY reader will be familiar with these three states of water; but in this paper we propose to discuss the relations of the three states, and the laws according to which water passes from one state to another.

We all know that when we heat ice it melts and becomes water. If we continue the application of heat, the water gets warmer, and begins to give off steam, but up to a certain point only slowly. Continue the heating, and a sudden change takes place; the water "boils." Steam is then given off much more rapidly, until the whole of the water is turned into steam, or "boiled away." These are the phenomena as observed by every one. When we want to find out a little more about what takes place, we must not be satisfied with mere "observation," but must refer to "experiment." Now, experiment differs from observation in this way: When we observe, we merely look at the phenomena in their natural state; when we experiment, we reproduce the phenomena under artificial conditions, and endeavour to separate the different causes which produce them.

Let us take an instance. The motion of the earth is influenced by a great many causes. Among them are the attractions of the sun, of the moon, and of other planets. To determine what influence each separately has, we have only "observation" to guide us, as we cannot "experiment" with planets. We must be content with seeing the effect when two of the disturbing forces act in the same direction, and again when they act against each other. We cannot modify any of them.

Suppose, however, we have a cistern being filled at a given rate by two pipes, A and B, and we want to see what proportion of the inflow of water is due to each pipe. We can close pipe A, and observe the rate of filling by B alone; and then we can close B, and observe the rate of filling by A alone.

But to return to our ice. We have observed that the ice melts when heat is applied. We want to know how much heat it takes to melt a given piece of ice. But before commencing any heat-measurements we require a means of knowing the *temperature* of whatever substance we are experimenting on. We have such a means in the *thermometer*.

The most common form of thermometer consists of a glass bulb attached to a fine glass tube (Fig. 1). The bulb and a portion of the stem are filled with some liquid — either mercury (quicksilver), or spirit. When the bulb is heated the liquid expands, and a portion of it is forced into the tube.

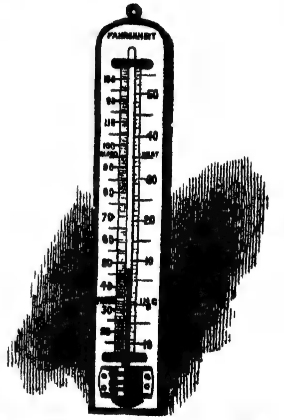


Fig. 1 —The ordinary Form of Thermometer, with Fahrenheit and Centigrade Scales.

The temperature of any liquid can be observed by placing the thermometer in it and noting at what point of the tube the end of the mercury-column stands. If the liquid is heated, the thermometer is also heated, and the end of the column rises; if it is cooled, it sinks, while if the temperature remains constant, the head of the column remains stationary. Now, on a very cold day let us take some ice, break it up, and put it in a saucepan, and put the thermometer so that its bulb is well surrounded with ice (Fig. 2). Then let us put the saucepan on a slow fire and watch the thermometer. The ice will not immediately begin to melt, but the mercury will begin to rise,* and will go on rising steadily for a little. Soon, however, the ice will begin to melt, and directly this occurs *we shall see that the mercury*

* To ensure success in this experiment, the ice should be pounded small and kept stirred with the thermometer; this prevents one part getting hotter than another.

*will stop rising, and will remain stationary till all the ice is melted.* That is, the contents of the saucepan do not get any hotter, for all the heat that is applied to them, until all the ice is melted. This shows us that when once melting is begun, the whole of the heat received from the fire is spent in

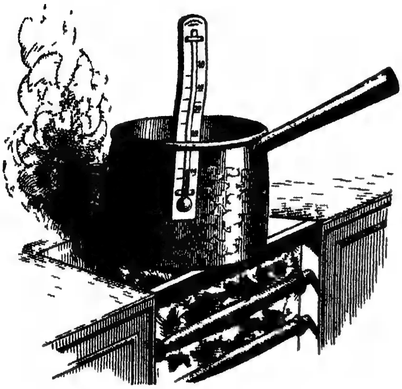


Fig 2.—Experiment illustrating some Phenomena connected with the Melting of Ice.

melting the ice, and none of it in making the water or ice hotter. Let us make a mark on the stem of the thermometer, where the mercury stands during the melting of the ice.

Now let us repeat the experiment with some more ice, and vary it in any way we please. We shall find that, however often we try the experiment, the mercury will always stand at the same point, which shows us that the *temperature at which ice melts is always the same.** Now let us suppose our ice all melted, and the heating to continue. The mercury rises again—which means that the water is getting hotter—and it goes on rising till the water boils. Directly boiling begins, the mercury stops rising, and rises no more until all the water is boiled away.

Next let us repeat this portion of the experiment on different days. We shall find that the point where the mercury rests while boiling goes on, is nearly the same in the different experiments, but not exactly. Thus at the same place, but on different days, water boils at very nearly, but not quite, the same temperature.

Now, however, let us try the experiment first at the sea-level, then half-way up a mountain, and then at the top. We shall find that as we get higher above the sea, water boils at a lower temperature, and when we get to the top of a very high mountain, it will boil when only tepid. The reason of this will be seen when we think a little what boiling is. Water is always, even when cold, *trying to turn into steam and expand in that form.*

It is, however, prevented from doing so by the *pressure of the air.* We know that the air at the sea-level presses on everything with a pressure of about 15 lb. to the square inch. The reason why things are not crushed, is that the pressure is equal in all directions.

If we take a bottle, say an ordinary medicine-phial, and cork it up air-tight, there is an outward pressure of 15 lb. on every square inch of it This,

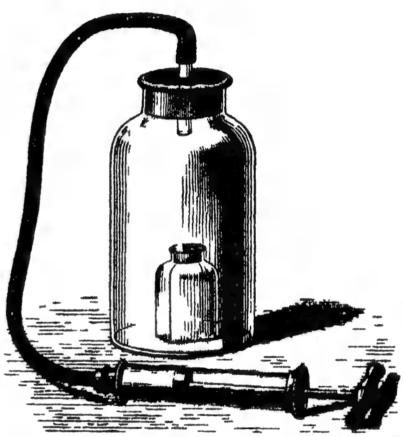


Fig. 3.—Experiment to illustrate the Pressure of the Atmosphere.

however, does not strain the glass, as there is an equal and opposite inward pressure exerted by the air outside. If, however, we put the bottle inside a larger bottle, or jar, and pump the air out of the latter, then the outward pressure of the air in the bottle will no longer be balanced, but will either burst the bottle, or drive out the cork (Fig.3). Well, this pressure resists the tendency of the water to turn into steam. When, however, the water is heated, it trys harder and harder to turn into steam, till at last a point is reached where the outward pressure of the vapour of water just overbalances the inward pressure of the air, and then the water boils freely.

Now we begin to see why water does not always boil at the same temperature. Water boils when the outward pressure of the steam balances the inward pressure of the air, but the latter is not quite the same on different days. We know that the *barometer* is an instrument for measuring the pressure of the air. When the air presses heavily, the column of mercury rises; when lightly, it sinks. That is, the air presses harder when the barometer is high than when it is low.

This enables us to understand why the barometer

* There is a small difference if the ice is subjected to great pressure

does not stand at the same height at all times even at the same place. When, therefore, the barometer is low, it means that the column of air over the place of observation is lighter than when the barometer is high. Therefore, when the barometer is high, the steam will have to exercise greater force to overcome the pressure of the air than when it is low: so if the water boils at a certain temperature when the barometer is low, it will when the barometer is higher have to be heated more before the steam gets up pressure enough to overcome the pressure of the air.

Similarly, in going up a mountain the barometer falls, because there is a shorter column of air above a point half-way up a mountain than there is above one on the sea-level. Now as there is at the high level a shorter column of air, its pressure will be overcome, and the water will boil, by a much smaller pressure of steam than at the low level; and therefore *water boils at a lower temperature on the top of a mountain than at the sea-level.* Numerous experiments and calculations have been made, and a table has been constructed by which the height of a mountain can be determined by observing at what temperature water boils at its summit. This method is not quite so accurate as observation with a barometer, but in exploring new countries it is easier to carry a small tin saucepan and a thermometer, than it is to carry a mercurial barometer.

We can by means of an *air-pump* even make nearly cold water boil. If we put a glass of water inside an air-tight glass bell and pump the air out, the water, though only just tepid, will boil freely. Quite cold water cannot be made to boil in an ordinary air-pump, because the vapour of water that is given off before boiling commences prevents us from ever obtaining anything like a perfect vacuum. I do not doubt, however, that with a very large air-pump driven rapidly by a steam-engine, water could be made boil when only a few degrees above freezing.

Here is a paradoxical experiment, in which we make water in a flask boil by pouring cold water on the flask, and stop boiling by heating the flask. To perform the experiment, boil some water in a flask for some time till all the air is driven out; cork it up, and invert it. The boiling will stop in a moment or two. If now some cold water be poured on the flask, it will condense some of the steam and make a partial vacuum, which diminishing the pressure, the boiling will start again. On heating the flask, the pressure of the steam will increase and the boiling stop.

We may add that—contrary to the popular belief on the subject—there is almost no limit to the temperature to which water can be heated in closed vessels when the pressure of the steam prevents it from boiling. In locomotive boilers the water is often heated to between 300° and 400° Fahr. In a sufficiently strong vessel water may be heated to a temperature equal to that of red-hot iron.

Experiment shows that when the barometer is at the same height, water always boils at the same temperature. The temperature at which water boils when the barometer stands at 29·905 inches in air at the freezing temperature is taken as the standard boiling-point.

Here, then, we have two temperatures which are always constant, and which can be easily determined —viz., the temperature of melting ice, and the temperature at which water boils when the barometer stands at 30 inches. These are marked on the stem of the thermometer, and the space between them being divided into a given number of equal parts, intermediate temperatures can be observed.

Fahrenheit divided the space between these two points into 180 equal parts, and numbered the lower one 32°, and the upper 212°, so we say that ice melts at 32° Fahrenheit, and water boils at 212° when the barometer stands at 30 inches. In the Centigrade scale the lower point is called 0°, and the upper 100°, but we will use the Fahr. scale in this paper, as it is likely to be more familiar to our readers.

We have seen that a good deal of heat is expended in melting the ice, and that until all the ice is melted none of the heat is spent in making the water warmer than 32°. Similarly, a good deal of heat is spent in changing the water at 212° into steam, at the same temperature. None of this heat is employed in heating either the water or the steam; it is all expended in producing the change of state.

We are now in a position to return to our determination of *how much* heat is used in each case. To measure anything we must have a unit. To measure a length, we have a unit called the yard, and we can compare different lengths by saying how many yards each of them contains. To measure a liquid, we have a unit called a gallon, and we can compare different quantities of liquid by saying how many gallons each contains. But how are we to have a unit of heat? It is found that within certain limits the quantity of heat which is required to heat *a given quantity of water through a given number of degrees of temperature is always the same.*

So we take as our unit of heat the quantity of heat which will heat 1 lb. of water 1° Fahr. It is found by experiment that to melt 1 lb. of ice requires no less than 144 units of heat; or the quantity of heat which it takes to melt a piece of ice would raise the temperature of the same weight of water 144° Fahr. It is also found that the heat required to evaporate a pound of water is equal to 967 units, or that the quantity of heat which it takes to boil away a quantity of water could raise the temperature of 967 times that quantity of water 1° Fahr.

Water, when all converted into steam, occupies, when the barometer stands at 30 inches, about 1,650 times its former volume. It must be remembered that steam is an invisible vapour. The white clouds which often accompany it are due to partial condensation.

And now let us see what happens when we reverse the processes we have just gone through. Let us suppose that, instead of allowing our steam to go up the chimney, we collect it all in a vessel from which no heat can escape, and then condense it: we shall find that the steam in condensing gives out *exactly as much heat as the water absorbed during the process of boiling away.* That is, the heat which 1 lb. weight of steam gives out in condensing would heat 967 lb. of water 1° Fahr.; or, what is the same thing, $96\frac{7}{10}$ lb. 10°. These seem enormous figures, but the experiment is one which any one can try roughly. Get a large kettle, and put 1 lb. of water into it (Fig. 4). Water can be easily weighed by counterpoising a jug or glass on the scales, then adding one pound to the weights, and pouring in water till the balance is restored. Now make the lid air-tight with a little putty, and jam a bit of wood between it and the handle, to hold it down. Attach a *long* india-rubber tube to the spout, and let it go into a wooden tub containing cold water.* Let there be tube enough to make *at least* a dozen coils in the tub. Put into the tub 97 lb. of cold water—that will be about $9\frac{3}{4}$ gallons. Put the kettle on the fire, tilted back so that the spout may be clear of the water. Take the temperature of the cold water carefully, say it is 60°, cover up the tub with some blankets to prevent heat escaping, and wait till all the water is boiled away. Now take the temperature of the water in the tub again, and you might expect to find, if you have done your experiment carefully, that it is just 10° higher. The increase of temperature will, however, be somewhat more, for we must remember that the condensed steam forms 1 lb. of water at 212° which we have added to the $96\frac{7}{10}$ lb. of cold water, and this will raise its temperature, roughly speaking, $\frac{1}{97}$ (212°—70°), of about $1\frac{1}{2}$°, so we shall find that the whole increase of temperature is about $11\frac{1}{2}$°. That is, that the condensation of the steam from about $\frac{4}{5}$ of a pint of water has heated $9\frac{3}{4}$ gallons of water $11\frac{1}{2}$

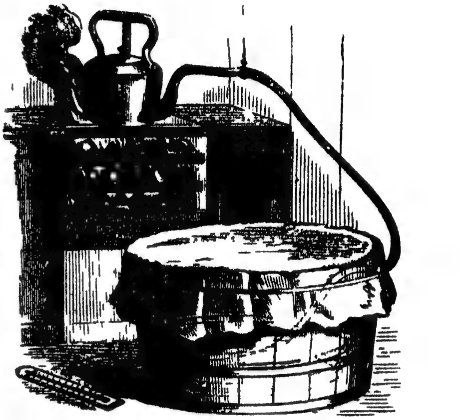


Fig 4 - Experiment showing how Steam in condensing gives out a certain Amount of Heat.

instead of $9\frac{3}{4}$ gallons, we had only, say, 2 in the tub, it would have been heated some 55°, or the steam from $\frac{4}{5}$ of a pint of water would heat 2 gallons of cold water so that you could just bear your hand in it. You must not expect very great accuracy in these measurements. The experiments on which the numbers are based were made in laboratories with all manner of elaborate contrivances for preventing escape of heat, allowing for heat absorbed by containing-vessels, &c. They will, however, give a fair idea of the enormous quantity of heat required to change water into steam, and given off again when the steam condenses.

Having thus condensed our steam, let us go on cooling the water till it begins to freeze, and note the process that takes place. Small needle like crystals begin to form, some sticking to the bottom and sides of the vessel, some on the surface of the water; but we observe that all the bits of free ice *float.* Why is this? Each weighs, of course, exactly the same as the water from which it has been formed. In order that a body may float in water, it must be lighter than its own bulk of water, or, what is the same thing, *larger than its own weight of water.* That is, the ice must have *expanded* in freezing. To show directly that this is the case, fill a bottle quite full of water, cork it up, and wire down the

* A bit of stick and string from the chimney-piece will be found useful to keep the tube away from the fire

cork. On freezing the water, the bottle will be broken. The expansive force of ice in freezing is enormous. Opticians sell small cast-iron bottles half an inch thick. These being filled with water, an iron stopper is screwed in, and the whole put in a freezing-mixture. On the solidification of the water, the bottles are invariably burst.

When water is enclosed in still stronger bottles, so that it cannot expand, it can be cooled much below the freezing-point without solidification taking place. The breaking-up of porous rocks is much hastened by the expansion when it freezes of the rain-water which fills the cracks in them. Water, like all other bodies, contracts as it is cooled; but just above the freezing-point it begins to expand, and expands till it is solidified. The ice, once formed, contracts as it cools, like any other solid body. The point of *maximum density* of water—that is, the temperature where contraction ceases, and expansion sets in—is about 39½° Fahr. Water shares this property of expanding at the moment of solidification with bismuth and some other substances. Cast-iron possesses this property in a small degree, hence the sharpness of iron castings, as the expansion at solidification fills every part of the mould.

Under certain circumstances, ice does not behave as a solid, but as a viscous fluid, like *very* thick treacle. Glaciers do not move down in one block, but *flow*, accommodating themselves to the varying width of their channel. Professor Tyndall planted a row of sticks in a straight line across a glacier; and after a few days the line had become a crescent, with the concavity upwards, showing that the middle of the glacier moved faster than the sides, just as in a river the stream is stronger in the centre. Two theories have been put forward to account for the viscosity of ice; one is, that it is a true viscosity, and the other that it is produced by the effect of pressure in lowering the freezing-point of water, so that whenever the ice is subjected to great pressure it melts. The water then yields to the pressure, and instantly re-freezes in its new shape.

A striking experiment—due, I believe, to Mr. Bottomley—illustrates this. A block of ice being laid across the backs of two chairs, a fine iron wire is put over it, to which is hung a heavy weight. In a short time, the wire passes completely through the ice, and allows the weight to fall, while the ice is not broken, nor is any mark visible where the wire has passed through (Fig. 5).

The explanation of this is that the pressure of the wire melts the ice immediately below it. The water is displaced by the wire, and fills the space above it, where, the pressure being removed, it instantly re-freezes.

The viscosity of ice can be shown by cutting a long, thin slab of ice, and supporting it on two chairs, when it will, even in a temperature below freezing, gradually bend with its own weight.

If the reader has followed the experiments, and deductions from these experiments, described in the foregoing pages, he should have learned in the first place that there is a difference between observation and experiment. Then he will have seen that a good deal of heat is required to melt ice, and that also much heat is spent in converting a piece of ice into water at the same temperature. He will have also learned how temperature is indicated, and thus,

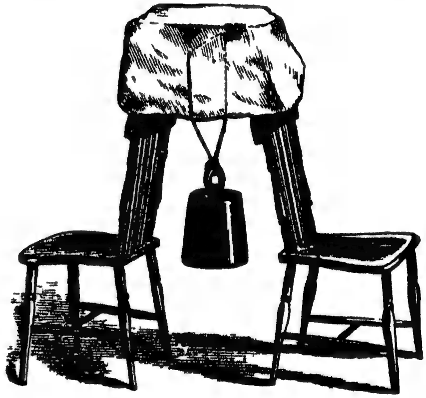


Fig. 5.—Experiment demonstrating the Melting of Ice under Pressure, and its Re-freezing.

incidentally, the theory of the mercurial thermometer. The temperature at which ice melts, except when it is under great pressure, has been shown to be always the same. But the temperature at which water boils varies according to the height of the barometer.

Water boils when the expansive force of the steam overcomes the pressure of the air. Hence the height of mountains can be calculated from the temperature at which water boils on their summits, for at a given height of the barometer water always boils at the same temperature. It has also been demonstrated that a great deal of heat is required to convert hot water into steam at the same temperature. Quantities of heat are measured; the unit of heat is the quantity of heat which will raise the temperature of one pound of water one degree Fahr. It takes 144 units of heat to melt 1 lb. of ice, and 967 units to convert 1 lb. of water into steam. Steam at the same pressure of the atmosphere

occupies about 1,650 times the volume of the water from which it is produced. On condensing steam or freezing water the same quantity of heat which was required to produce the change of state is now given off in the reverse process. Water expands when freezing; the point of maximum density—that is, the temperature at which a given weight of water is smallest—is 39½° Fahr. Water exercises enormous pressure in freezing, and will burst strong iron vessels. When the vessels are strong enough to resist pressure, freezing is arrested, and the temperature may be reduced much below 32° Fahr. before solidification takes place. Finally, in this paper the writer has endeavoured to show that ice is not rigid, but viscous, like tar, honey, or treacle, as proved by the well-known fact that a glacier flows like a river—faster in the middle of the stream. This may be either true viscosity, or else it may only be that where the pressure is greatest the ice is temporarily melted.

## A HIGHLAND GLEN.

By Robert Brown, M.A., Ph.D., F.R.G.S.,

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It is autumn, and we are sitting on the hill-slope overlooking a Highland glen. It is one of those deep and wildly-romantic valleys that run seaward along the western shores of Scotland, to terminate in a deep loch, inlet, or fjord, which is to all intents and purposes the exact counterpart of the glen we have been travelling through, except that where in the loch there is sea, in the glen there is land. The scene has been painted a hundred times. The misty morning clouds that have hung over the hills since dawn are now lifting up, and opening out the view seaward and landward. Westward, there is the loch, with its sunlit surface, and its white sails, the full extent of it concealed by the wild heathery capes, round which the fog still hangs, grey and ghostlike, as if loth to leave a scene so peculiarly in keeping with it. Out of the mist comes the cry of the sea-mews, mingled with the whir of the grouse which are flushed from the heather at our feet; while afar we can hear the distant echo of the waterfall ceaselessly splashing into the sea. Landward, the scene is wildly peaceful. The eye meets only mountain after mountain, the highest beginning to be tipped with the early snow, while the fading heather flowers give a reddish-brown aspect to the surface. A few cotters' thatched huts smoke down in the valley; a few dwarf sheep or long-horned, shaggy Highland cattle, graze here and there. But beyond this the land is yet in a state of nature. For all of the signs of man and his works around us, we might be in some Rocky Mountain valley, or looking on a scene in the Scandinavian Nordland. But we are at present studying the landscape not from the painter's or the poet's point of view. Pleasant no doubt it is—

> "To roam at large among unpeopled glens
> And mountainous retirements, only trod
> By devious footsteps; regions consecrate
> By oldest time; and while the mists
> Flying, and rainy vapours, call out shapes
> And phantoms from the crags and solid earth;
> . . . . and while the streams
> Descending from the region of the clouds,
> And starting from the hollows of the earth,
> More multitudinous every moment, rend
> Their way before them. What a joy to roam
> An equal among mightiest energies." *

It is our business, however, to analyse that scenery—to shut our eyes for the time being to the harmonious whole, and to investigate the elements of which it is composed. Now, in doing so, we are at once struck by the smoothed, shaved, or rounded aspect of many of the rocks. Rain, wind, rivers, and weather in every form, have been ceaselessly at work moulding the mountains at their will. The rocks are accordingly worn in various fantastic forms, according to the facilities they give for the elements acting on them. They crumble away in sharp peaks, in rounded knobs, or in the low, stair-like appearance so characteristic of whinstone. Here, however, the mountains seem mostly composed of granite, or what for our purpose is much the same; and the surface is everywhere, especially on the lower grounds, rounded and smoothed, as if it had been subjected to the action of some great file. Scattered over their surface are blocks of rock.

* Wordsworth: "Excursion," Bk. iv.

covered with the motley-coloured lichens, and weighing in some cases many tons. Most of these blocks have sharp edges, and seem to have undergone no rough usage save what the weather has inflicted on them. Others, however, are rounded; their sharp edges are worn off, so that in many instances they seem as if they had been rolled round and round until they have attained their present shape. Some of them are scattered on the hills hereabouts; in fact, we are sitting on one. But if we travel down into the glen, and stand in the bed of the "burn" or rivulet which runs through it on to the loch, we shall see still more. Indeed, this stream—now so quiet as it trickles along through its almost dry bed, but which we can see, from the broad, rugged path it has worn for itself, is a wild ravager from the mountain when swollen by the melting snow of spring—seems to have cut its way through among these rounded blocks or "boulders." The whole soil is full of them, little and big, and the water which has washed away the clay now gurgles and splashes in, about, and over them.

But if we examine them further we detect something still more startling—viz., that many of them are of rock not the same as that on which they

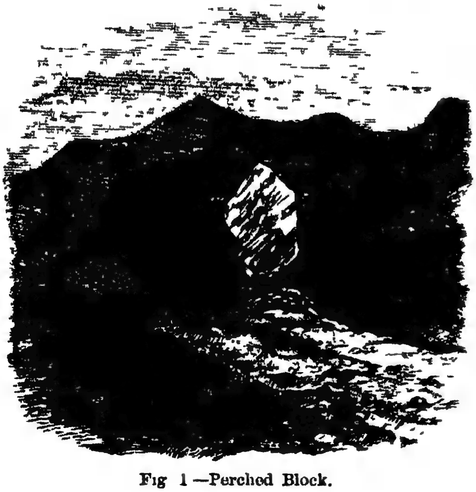


Fig 1 —Perched Block.

are lying, often perched in strange positions (Fig. 1). The rounded boulders in the clay down on the banks of the burn in the glen are generally of the same rock as is found in the vicinity, or at least within a few miles. But the perched blocks on the hills around, or scattered about here and there, are, in the greater number of cases, rocks that are strange not only to the country about, but even to Scotland. Indeed, if you are a traveller, you may detect in many of them, rocks which are not found nearer than Norway. This is a discovery, then: the blocks of stone are travellers, strangers to the neighbourhood, and, though naturalised, not of Scottish birth.

The next thing we observe is that all or nearly all of the round boulders are scratched or polished in certain places, as if some giant had rubbed them with a Titanic file, and thereafter applied sand-paper to the place, without, however, effacing the file-marks (Fig. 2).

The geologist must be a philosopher of the peripatetic school; and accordingly, if we wish to ascertain anything accurate about the history of this weird-looking Highland glen, we must not be sparing of our legs. We again climb the hill, and examine the rocks around. Beyond being rounded and knoll-like here and there, we at first sight observe nothing very peculiar. But just as we are sitting on a smoother place than ordinary, we detect on the surface of the rock scratches and polishing very much the same as that which we saw on the boulders below. The scratches are, however, usually deeper —in some cases being more like the furrows made by drawing a garden-rake over a firm, soddened piece of soil, than mere scratches. In other places, the surface is absolutely smoothed, and even polished, where the material acted upon is sufficiently hard to have taken this on. In other spots, the scratches are almost effaced by the action of the weather on the rock, or by the corroding action of the lichens. Now that we have once discovered these scratches, we seek eagerly around for more, and as likely as not find them plentifully and well preserved by pulling up the thin, hungry Highland turf that in the course of ages has accumulated over them, and protected them from Time—that *edax rerum*—rock scratches included.

Generalisation in geology from a few facts is a dangerous if seductive pastime. Still, in this case we are right, if we conclude, after an hour or two's search, that in this part of the country at least, most of the grooves and scratches take a determinate direction. They may occasionally cross each other, and in places look as if sand-paper, in which each grain was a pebble imbedded in a board, had given the rock a rough polishing. Still, the conclusion from a study of the average is that they all go in one general direction. In this case it happens to be westward, or to the sea.

But something has caught our eye down in the glen. We apply the field-glass to it. It looks like a sheep asleep among the heather—a black one, too,

albeit that breed is rather rare hereabouts. But no—it cannot be a sheep. We shout: the other sheep scamper off. We throw stones down on them, and they instantly show themselves sensible to such lithine persuasives. We roll a little boulder or two down the heathery slope, but the black sheep lying asleep among the heather—its back only appearing among the waving cotton-grass, blue-bells, and purple ling—remains motionless, though our missile rushes down the hill-side, through the boggy pastures, and splashes into the burn with a sound that gathers voice and echoes among the silent hills. If it is a sheep, it is perfectly certain that it is a deaf or a dead one. Finally we do, what we ought to have done at first; we pay the black object a visit. Then we discover the secret of its silence—the mystery of its immobility. It is a large black boulder, firmly imbedded in the soil, or perhaps only a piece of the mountain rock appearing above the surface. But, at a distance, it certainly looks wondrously like a sheep. This is owing to the fact that it, too, is smoothed, and perhaps polished also, as if some great flood had for ages been pouring over it; or, better still, as if some more or less solid body had been squeezing and grinding it on its course down the valley; for it is clear that, whatever has been the grinding agent, it has moved seaward (Fig. 3).

We have now learned so many facts—or what we suppose to be facts, for in geology the last thing the man who has not learned to look should do is to "trust his own eyes"—that we had better pause and master the data, before the data master us. What, then, have we learned? Simply this—(1) That in and about this Highland glen there are certain rocks lying solitary, detached—not belonging to the immediate neighbourhood, and in many cases brought from a great distance. (2) That many of the rocks are scratched, grooved, and polished as if some body capable of leaving an impression behind it had passed over them; that these markings are found on the rocks high and low; that the markings are all in one general direction, as if the body had been moving seaward; and that, last of all, it is evident that the markings—from those on the rocks at the top of the hill, to those on black-sheep-like rocks among the heather down below—were caused by the same agent, whatever that might have been. These are facts: there is no getting over them. The next question is, What agent brought the rocks here from a distance? Here is a native of the glen, who has lived in it, "man and boy"—shepherd and sheep-farmer—"seven-and-sixty years come next shearing-time." Perhaps he knows something about it? The reader will at once perceive, from our credulity as to the knowledge of the glensman, that we are, however sharp in Capel Cour or in Chancery Lane, very ignorant of the character of Highlanders, and that our knowledge of physical geography is extremely elementary. "Oh, yes! he knows all about it;" and then, after ascertaining all about us—where we have come from, and where we are going to—he enlightens us:—"A witch, who lived in the old times in Tramowhusky Strath, was carrying some chucky-stones to Glen Mutchkin, and just hereabouts her apron-strings broke. Anyhow, that is what his father told him, and he had lived in the glen eighty-nine year; though old Donald M'Alpine did say how it was the stones that one giant threw at another that lived in Skye, that fell short here, and——"

It is evident that the worthy drover's geology is even more elementary than ours, and we endeavour to think it out for ourselves. What brought the stones here? Wind? That may be at once dismissed. The wind is gusty enough in the glen, but it is scarcely equal to blowing a shower of fifty-ton boulders from the Grampians, far less from Norway. Water? This is more likely. But though it might have rolled the boulders in the valley down to where they lie, it could never have tossed them upon the top of the highest hills, and perched them in all manner of peculiar places, sometimes even balancing them neatly on the points of other rocks, where they swing gently in the wind, as they have swung, to all appearances, for ages—and eons—past (Fig. 1). Moreover, there are no signs of water hereabouts. If we examine the clay on the cutting which the burn running through the glen has made for itself, we see nothing which would lead us to suppose that the clay or heterogeneous mass of stones on either bank had been subjected to the action of water; while the rocks perched high on the hills bear no signs of having been worn by either the waves, or in the bed of a river, or by any kind of current rubbing against them. Besides, there is the fact of some of the blocks having been brought from over the sea. It would be absurd to suppose that rock was ever, like St. Cuthbert's stone coffin, capable of floating on the surface of water. This is reserved for monkish miracles, and we are endeavouring to exercise our reason. So there is no common ground between us and the monks, any more than there was between us and the witch-believing Highlander who was our first guide and meant to be our philosopher and friend. We "give it up." We have

exhausted all the reasonable moving agents within our knowledge, and still have not explained the groovings, scratchings, and polishings on the rocks. For it is very probable that the scratchings are in some way connected with the travelled blocks, if the same agent that brought these stony voyagers here did not leave the scratched records of the fact on the rocks also. It is perfectly certain, however, that these scratches, &c., were made either before the travelled blocks of stone were deposited where they are, or about the same period, otherwise the agent that smoothed the rocks would have swept away the boulders upon them. It is therefore evident that mere guessing is a waste of time, and if the reader has already fathomed the mystery, he must be considerate enough to pardon the writer for under-estimating his acuteness.

Fig 2—Rock Scratches.

Next year we are in Switzerland, and spend some time in examining the glaciers in that country. The glaciers are great masses of land-ice, moving down from the mountains, filling up the valleys, and descending to the low grounds, until the warmth of the climate melts off the lower end, and thus counterbalances the force that causes them to move from above (Fig. 4). This, for the present, is sufficient for our purpose; by-and-by we may have a great deal more to say about glaciers. On the surface of these glaciers we see moraines—that is, earth, gravel, and rock which have fallen on the sides of the glacier, and been carried from high up among the Alps, miles and miles on the snowy surface of the glacier, until, by the melting away of the end of the glacier, they have been stranded down among the vineyards and pastures of the lower valleys. There to this day you can see them scattered about. The very peasants recognise them as not belonging to the neighbourhood, and style them jocularly "foundlings." At the place where the end of the glacier was melted away we see a little of what was under the glacier. There are masses of mud, stones, and blocks of rock, which, owing to their having got frozen into the under surface of the glacier, have been rolled over and over in the course of its journey, until they are now more or less rounded, or at least have their sharp edges worn off. Again the guide—that omniscient man—will take us into Alpine valleys, out of which, owing to a change of climate or other causes, the glaciers have long ago disappeared, only leaving their traces behind. There we see the travelled blocks and the rounded boulders, but we also observe something which strikes us as strangely familiar, and recalls a Highland scene of twelve months ago. We see the black-sheep-like rocks rising, back up, above the pasture. We examine them, and find them in every respect identical with those we saw last year in the Highland glen (p. 35). To our astonishment we find that these rocks are known to the Swiss as *roches moutonnées*, or "sheep-rocks," and that their shape is due to old glaciers having passed over them when those ice-rivers crawled down the valley we are standing in. There are the scratchings and groovings, and indeed, on every rock where the glacier has passed over, we find the same marks, identical in every respect with those we saw on the Highland hills. We see how they have been formed. Stones and gravel have got frozen into the under surface of the glacier, and have ground the rocks over which the glacier had

Fig 3—Sheep-Rocks.

passed, just in the same way as if the glacier was a huge file, many miles in length, and half a mile in breadth, moving with an impetus that carried all before it. All around us we see the effects of this great file, working down the rocks and soil in that "eternal grind." From under the glacier a stream, formed chiefly of the melted snow which has fallen through the cracks of the glacier, is ever flowing. This stream is milky in colour, and deposits, if allowed to settle, a fine mud, which it holds in suspension. This mud is, in reality, the rocks powdered into dust by the moving glacier.

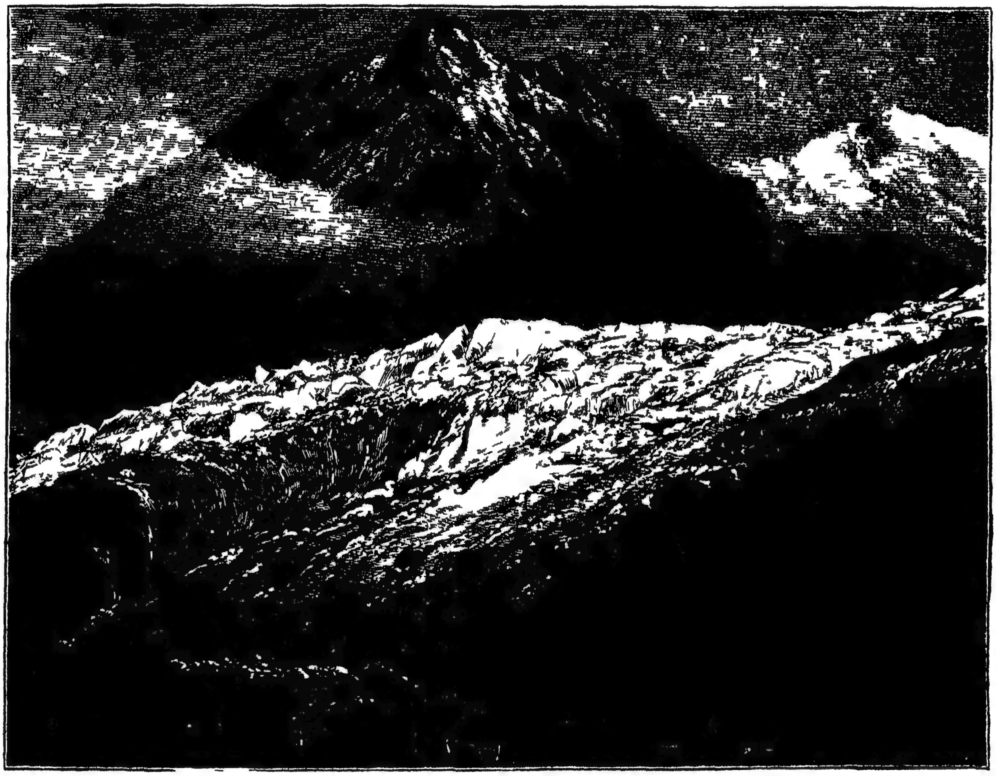


Fig. 4.—Glacier on the Susten Pass, Switzerland, showing the Moraines.

Light is dawning upon us! We return to the Highland glen, as if we had received a revelation from our visit to the Swiss one. It is perfectly apparent that to ice must be due the boulders scattered over the hills, the "sheep-rocks" in the glen, the mass of rounded boulders on the banks of the "burn" down below, and the scratches on the rocks. But still there are some things not altogether clear yet. For instance, we cannot well understand how the perched blocks got to the top of the hills. If they had been deposited by glaciers, would they not have been down in the valleys?

Another fact is discovered by us on our second visit to this Highland glen. As we are passing through the valley we examine the banks of the stream flowing through it. On each side we see a cutting displaying the character of the soil. It is filled with rounded boulders,* bits of rock, &c. —all from a few miles around—but this is *débris*, arranged without any relation to the weight of the materials, showing that the materials were placed there not by the action of water. Moreover, we find in this mass stones scratched and polished, and—take it all in all—there seems strong reason to believe that it is the exact counterpart of the material we got a glimpse of under the Swiss glacier.

But lower down the valley, indeed along the shores of the loch itself, we come upon another deposit. It is a whitish fine-grained clay, identical with that which we have seen the brick-makers using for moulding. Here there is no longer any doubt about the action of water. The clay is finely "laminated" like the leaves of a book, the heavier materials lowest, the finer uppermost. So far so good, and we might pass on; but in digging

* Hence known to geologists as the "Boulder-clay."

into it we disinter shells—sea-shells—of forms not unfamiliar to us. If we take them to a museum, we shall soon see that they are of species now living, but not, or rarely, in the seas round our islands. Here are a few of the more common ones, which we have dug out of the clay along the loch-side (Fig. 5):—

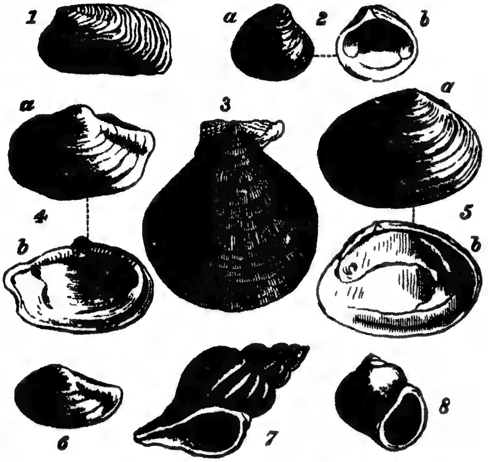



Fig. 5.—Arctic Shells found in the Scottish Glacial Clays.

1. *Saxicava rugosa.*
2. *Astarte borealis* . . . { a. Exterior of Valve. b. Interior of Valve.
3. *Pecten islandicus.*
4. *Leda truncata* . . . { a. Exterior of Left Valve. b. Interior of Same.
5. *Tellina calcarea* . . . { a Exterior of Left Valve. b. Interior of Same.
6. *Leda lanceolata.*
7. *Trophon clathratum.*
8. *Natica clausa.*

A further examination soon shows that they are shells now found commonly in the seas of Greenland, Spitzbergen, and other Arctic countries. These facts show—first, that at one time what is now land must have been sea-bottom; and secondly, that at that time the sea around the Scottish shores must have been colder than at present, so as to allow these Arctic shells to burrow in the mud. Still, everything is not very clear to us, though the curtain has been lifting up since that day when we sat, ignorant alike of glaciers and geology, on the boulder in Glen Mutchkin. We can now see how the glaciers that once filled the Scottish glens deposited boulders in the valleys, and grooved the rocks; but yet we do not quite see the source of the rocks on the hills, nor of the beds of clay containing Arctic shells. Nor are we ever likely to know until we visit some great Arctic country like Greenland.

In the latter continental island, for example, you find the whole interior covered by one great glacier —swaddling hill and dale in one icy winding-sheet. If the traveller penetrates on it for a little way, he sees nothing before him but ice. There is ice north, and ice south; and if he goes far enough, he will see the black coast, the few miles of uncovered land surrounding this ice-covered interior plateau, fading away behind him as the coast fades behind the voyager sailing out to sea in a ship. Into the inlets, lochs, or fjords of the coast this great *mer de glace*—this mighty sea of ice—discharges itself in the form of icebergs (Fig. 6). Now, these icebergs are simply the ends of the glaciers broken off by being floated up by the buoyancy of the sea, and then falling off by their own weight. In the Swiss glaciers we have, of course, no icebergs, for long before the glaciers could reach the sea they would be melted by the warmth of the countries through which they would have to pass. But in these far northern latitudes it is different. There, glaciers form almost at the sea-level, and after a very brief course terminate in the sea. But otherwise the Alpine and the Arctic glaciers are identical. Each bears rocks, &c., on its surface, and each deposits them; but with the difference that, while in the Alpine glaciers the blocks and other ice freight are deposited in the valleys, where the glacier-end melts, in the Arctic ones the iceberg or broken-off end of the glacier, carries them to sea, and when the berg capsizes, deposits them on the bottom. In fact, the bed of Baffin's Bay and Davis Strait must be now strewn with such perched blocks, imbedded in mud, and thus subject little if at all to the wearing action of the waves. From under the Arctic glacier, as from under the Alpine one, there pours the milky river (p. 37). It flows, however, into the fjord, which it in time shoals up. In the mud deposited from the glacier-river the Arctic shell-fish burrow and live. Let us examine a bucket or two of this mud. To our pleasing surprise, we find it exactly the same as the old clay we saw along the Scottish loch-side, and in this clay are the same species of shells we found imbedded in that clay (Fig. 5). The very fjord itself is the counterpart of the Scottish fjord. It is curious that these inlets, as in Scotland, Norway, and North-west America, are always found on the western or moist sides of the country, where snow, the material out of which glaciers are made, is plentiful. Moreover, they are never found out of the latitudes in which snow falls. Hence there is every reason to believe that at one time they were the beds of glaciers, and, from being mere depressions, were hollowed into glens on land, and fjords

on sea, by the ever-grinding action of the ice passing through them.*

We have finished our study. We have led the reader on step by step, not concealing our difficulties as far as these are necessary to the right understanding of the subject in outline, and asking him to examine the different links in the argument. What, then, are the conclusions? These seem inevitably as follows:—That at one time Scotland was swathed in ice, as Greenland is now; that her valleys were filled with glaciers, which discharged icebergs into her lochs, then chilly enough for the Arctic shells to burrow in the mud deposited from the infra-glacier rivers, as is the case in Greenland at the present day; and that floating icebergs, or perhaps an Arctic ice-floe, at intervals deposited blocks of stone, now found perched upon the hills. This, of course, presupposes that much of what is now dry land was then under the sea, and *vice versâ.* But that is a fact so familiar that it is almost unnecessary to mention so elementary a bit of knowledge. Land at the present day is rising and falling slowly. Indeed, it is the stable sea and the unstable land—not the reverse, as we have been familiarly led to believe. The period during which all this happened is known to geologists as the "glacial period."† At that time the whole of the North of Europe, America, and perhaps of Asia, was covered by ice, and much of it was also under the sea. The musk-ox and the Arctic lemming lived in England, a woolly elephant roamed over the North of Asia, while the reindeer was a familiar animal as far south as

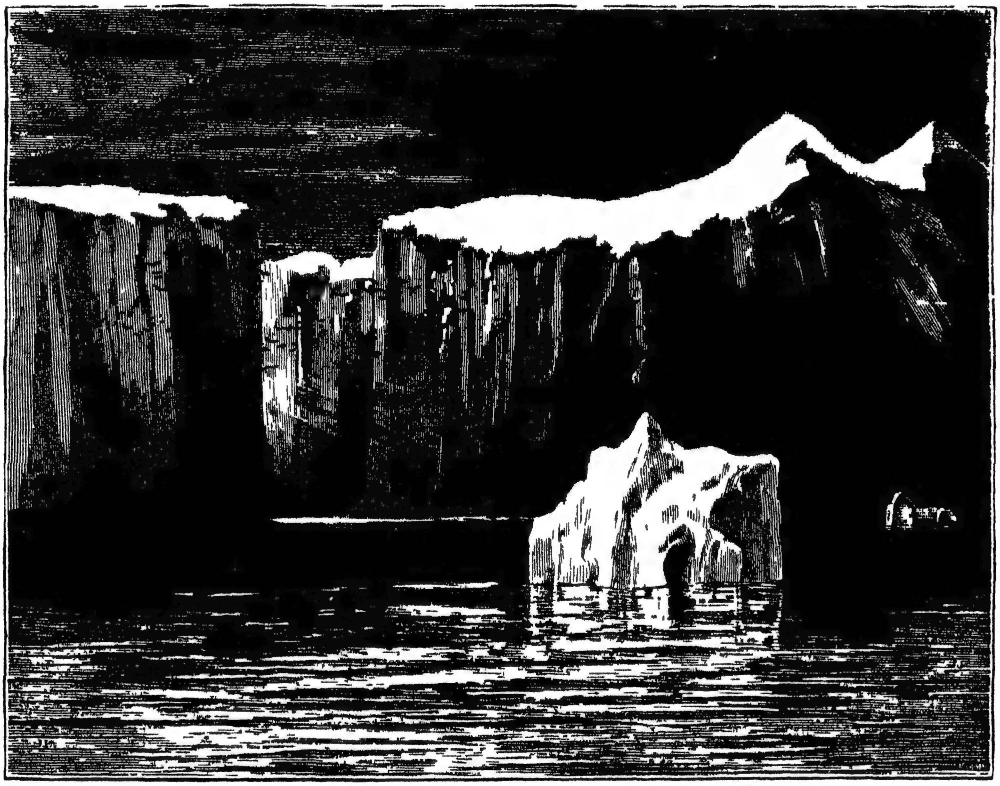


Fig 6—An Arctic Glacier and Icebergs (Sanderson's Hope, Baffin's Bay)

* In regard to which the writer may be allowed to refer the reader to his Essay on the Structure of Greenland, in "Arctic Papers of the Royal Geographical Society" (1875), pp. 1–73.

† There are few subjects on which there has been more discussion than the "glacial period," and scarcely two geologists have the same opinions on the same point. However, it is now universally held that such an epoch, or series of epochs, did exist, and that Scotland was subject to them. Some will even deny the presence of the universal ice cap in Scotland as in Greenland, and declare that sea ice, and icebergs with glaciers, did all the glacialation we see on the hills, &c. But these gentlemen reason from observations of an isolated and local character. Too much has been made of the "theory." Some very ill informed writers seem no more able to keep the "glacier theory" out of their books than Mr. Dick could keep King Charles I. out of his memorial. However, after an intimate acquaintance with glacialation both in the Arctic regions and in Europe and America, the conclusions given seem to us just.

France. Indeed, it is probable that at different periods in the earth's history there have been recurrent periods of cold, and that what we familiarly call the "glacial" period was the last of these—an epoch which, though chronologically very remote, is geologically almost immediately antecedent to man's advent on the earth. Indeed, it is by no means certain that man was not then living in Britain. There is no reason why he should not have been. He lives prosperous and even comfortable in Greenland, which is assuredly quite as icy as ever glacial Scotland was. What caused these changes in climate we do not know; and though the guesses have been numerous, and the theories many-worded, it is perhaps better to leave the reader for the time being in ignorance of them. We have seen how many remains of this glacial epoch exist in our own islands, but these are dead witnesses. Living ones are not, however, wanting. On the tops of the Scottish hills, on the summits of the Alps, the Pyrenees, the White, and the Rocky Mountains—and, indeed, of all northern ranges at about the same altitude—are found what are known as "Alpine plants." These are in reality Arctic plants, remnants of the vegetation which during the chilly period grew in the vicinity of the glaciers, and which, now that they have retreated to far northern latitudes, remain behind in these bleak retreats, as witnesses of that "Great Ice Age" of which they were denizens.

## WHIRLPOOLS AND WHIRLWINDS.

By William Ackroyd, Member of the Physical Society, London.

To hasten the solution of sugar when taking tea, we stir up the contents of the cup with a spoon. The crank-like movement of the hand gives to the fluid a circular motion, and we produce a small whirlpool within the cup. In this paper, we propose to deal with such whirlpools, be they small or great; and we shall afterwards extend our observations to the similar atmospheric phenomena of whirlwinds.

In order to see very plainly that a whirlpool is a body of fluid whirling round, let us take a glass tumbler instead of the tea-cup, and use water instead of tea. Put in little bits of coke, which by reason of their lightness will float on the surface, and then stir up again. The particles of coke career round and round the tumbler until the liquid comes to rest. If we watch any particular grain, it follows a course indicated by the arrows in Fig. 1. Observe that the particle when at *a* is moving towards the north side of the glass, and when at *b* it is going towards the south. The same fact we may state by saying that in a whirlpool the portions of fluid on opposite sides of the centre *c* are moving in contrary directions.

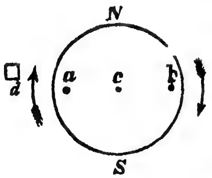


Fig. 1.—Diagram illustrating the movement of Bits of Coke in a Tumbler of Water.

If we imagine for a moment that our glass has swollen out to thousands of times its present size, and that one of the tiniest pieces of coke is a ship, or boat, in which we are borne round by the current, then our compass-readings would fully bear out what we have been now considering; for whilst at one time we should be going northwards, a little while after our course would be due southwards. What we have here pictured in our minds exists in reality among the Loffoden Islands, off the northwest coast of Norway. The Malström is a whirlpool a mile and a half across; the noise of its roar is heard for a great distance, and the small vessels that are so unfortunate as to get within its reach are sucked in and destroyed by the turbulent waters.

The reader may likewise have heard of the classical whirlpool of Charybdis, in the Straits of Messina; for, although far less dangerous than the Malström, it was feared exceedingly by the ancient mariners, who in their open ships were in great danger when once within its range. Appealing rather to their imaginations than to facts for the cause, they attributed it to the monster Charybdis, who was said to suck down the water thrice every day, and to throw it up thrice again. The true cause is not far to seek, for both in the case of the Malström, and in that of Charybdis, it is found in the contention of opposing currents of water.

Let us now take our flight to nature's opposite extreme; for we may there with a little trouble find whirlpools that are only *one thousandth part of an inch* across!

Attached to some fresh-water plants there is found

a very small animal, called by naturalists *Vorticella*, or the *bell-animalcule*. To make out its form one requires a good microscope, and it is then found to be like a bell, with a long, flexible, and contractile handle. Around the rim of the bell it sends out very minute thread-like processes, which it lashes vigorously backwards and forwards, producing by these movements the minute whirlpools we have just mentioned.

Fig. 2 gives some idea of this phenomenon. The observer sees small particles rushing towards the top of the vorticella; they are bent out of their course, and spin rapidly round . on one side in the


Fig. 2.—The *Vorticella* or Bell-Animalcule, producing Whirlpools.

direction of the hands of a watch, as at *a*; and on the other side in the opposite direction, as at *b*.

The tea-cup whirlpool is three thousand times wider than one of these, and the Malström sixty-three million times; yet these vorticella eddies are as perfect as either, the small food-particles which the animalcule is eager to get dashing round and round with as much uniformity as the bits of coke in our tumbler experiment. Nature's operations on the small scale are truly as marvellous as those on the large.

We may now pass to the consideration of whirlwinds—phenomena identical with those of whirlpools, but much more striking because of the greater mobility of air.

The main features of a whirlwind may be readily seen. We are out for a walk, and find ourselves on a dry and dusty road. A sudden gust of wind raises a dust-cloud near us. We plainly see the dust whirling round like the bits of coke in our tumbler experiment; but they are also borne along —they have, in short, a progressive movement. This, no doubt, has often been the reader's experience. The whirlwind characteristics, which he now recognises, are seen more strikingly still in the dust-whirlwinds of India, which have been minutely described by Dr. Baddeley. With a very short warning, the storm bursts upon the observer

Fig. 3.—Indian Dust-Whirlwind.

Everything is soon enveloped in darkness, and an enormous quantity of dust is sent up into the atmosphere. This is at times broken up into distinct columns, which rotate on their axes, and at the same time move over the ground. Fig. 3 represents such a column moving in the course indicated by the great arrow, and whirling round in the direction of the small ones—*i.e.*, in a direction contrary to that of the hands of a watch. The peculiarities of their motion will be well grasped by a moment's study of a peg-top. The top when hurled from the hand whirls round with great speed, and at the same time it has a motion of progression or translation, for it changes its place on the ground. Its movements may thus be graphically represented. If it starts at 1, it successively gains the positions 2, 3, 4, 5, and 6 (Fig. 4), all the time spinning round with great speed.

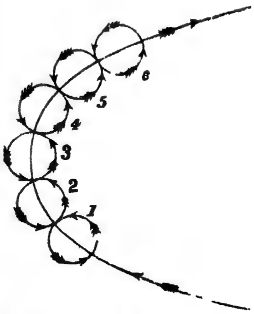



Fig. 4.—Diagram illustrating the Motion of a Peg-Top.

So likewise with the dust-whirlwind: whilst it rapidly rotates, it also gets over the ground.

In the Mississippi valley, whirlwinds are very

destructive: all along their paths the trees are felled as if an army of wood-cutters had been at work for many weeks. Maury remarks on this particular point:—"I have seen trees three or four feet in diameter torn up by the roots, and the top, with its limbs, lying next the hole whence the roots came." The same author further observes that the track of these tornadoes is seldom more than a few hundred yards broad. When we consider that in other parts of the world there are storms of a similar nature, which are as many hundred miles broad, their ravages on land and sea must be simply appalling. A storm of this kind, proceeding from the sea to the land, carries with it an irresistible storm-wave. Such a misfortune befel Lower Bengal in November, 1876. The islands at the mouth of the Megna were flooded to a depth varying between ten and forty-five feet, houses, trees, and human beings being swept away. In the districts of Chittagong, Noakholly, and Backergunj about 100,000 persons were drowned!

By the long-continued researches of many observers, it has been made out that the progressive motion of these dreadful whirlwinds or "cyclones" is a very leisurely one, being at the rate of two to thirty miles per hour, whilst the speed of rotation may attain to 100 miles per hour. The diagram we have already given to illustrate peg-top motion (Fig. 4) will likewise answer our purpose for cyclones, for they are essentially large bodies of air with the peg-top's rotation and progression on a greatly magnified scale.

We have already explained that particles on opposite sides of the centre of a rotating system are moving in contrary directions; the following peculiarity of cyclones will, therefore, be readily understood. When the centre of a cyclone travels over any particular place, there is a short lull, and the wind, which previously was tearing along in one direction, shortly blows in the directly opposite one. Suppose for a moment that Fig. 1 represents a cyclone whirling round in the direction of the arrows, and at the same time moving towards *d*, where an observer is stationed. As the centre approaches *d*, the first thing noticed is the due northerly direction of the hurricane; but when the centre has passed this point, the storm is observed to blow just in the contrary way.

The next phenomenon we have to study is a very interesting one, and is at the present time occupying much of the attention of scientific men. Conceive of a number of small whirlwinds being placed end to end, so as to form a ring of them—say, for example, four like *a b* in Fig. 5. Such a combination has some very curious properties.

The reader may readily make such rings, and trace their motion, by means of smoke. They are known as "vortex-rings." Take a cylindrical canister, say a clean lobster or mackerel tin. Get the tinker to punch a round hole just in the middle, and one-third of an inch in diameter. Now over the other end, which of course is quite open, tie a sheet of writing-paper. It must be tight, and as much like the face of a drum as possible. If smouldering brown paper be now placed within the tin, through the round aperture, it soon fills with smoke, and to produce rings it is only necessary to tap the paper end gently, when smoke-rings will issue with a speed proportionate to the strength of the tap (Fig. 6).

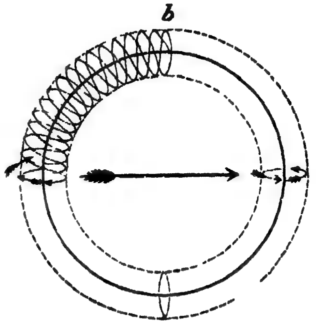



Fig. 5.—Vortex-Ring.

If the reader is desirous of making smoke-rings on a large scale—as, for example, to show to an audience—let him procure a tea chest. A round hole must be cut into the side opposite the open end, and over the latter a piece of canvas should be neatly nailed. Smoke is now required, and perhaps the readiest method of making it is the following:

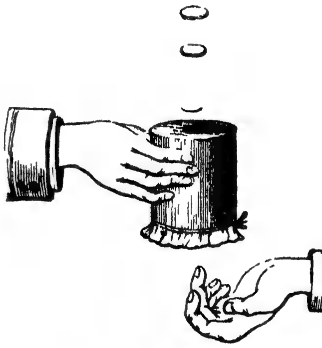


Fig. 6.—Small Vortex-Box.

Into one of the sides bore a couple of holes, just large enough to admit the insertion of two small glass retorts. Into one place hydrochloric acid, and into the other a solution of ammonia. Now heat the retorts with a spirit-lamp, or some other heat-source. The box becomes full of smoke of ammonic chloride—the chemical substance which

results from the mixture; and if the canvas be struck with the hand, large and beautiful rings issue from the round aperture.

We now possess a scientific instrument with which we can produce a certain phenomenon at pleasure—always a great step in the progress of discovery. Raleigh, as well as modern smokers, may have seen smoke-rings now and again issue from the bowl of his pipe, or originate from a puff sent out of his mouth; but such accidental phenomena take

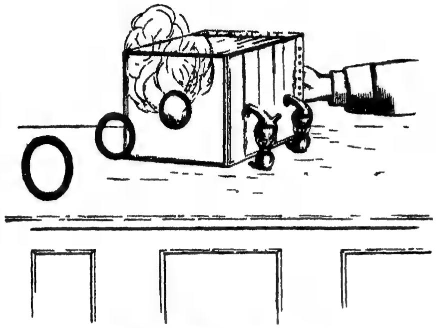


Fig. 7.—Tait's Vortex-Box.

one by surprise, and we scarcely know whence they come, and much less how they are produced. The very important step of making a piece of apparatus that would produce the phenomenon when wanted was first taken by Professor Tait. His apparatus is essentially that just described and figured (Fig. 7).

Having made the apparatus we have described, the reader would do well now to experiment on the nature of these smoke-rings.

The first thing noticeable is the motion of the smoke-particles which constitute the ring. Fig. 5 would make this plain; but to be more explicit still, imagine that one of these rings is cut in two—it would present the appearance given in Fig. 8.

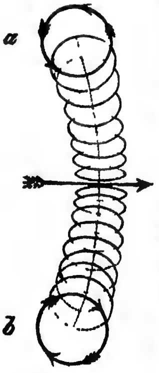



Fig. 8.—Imaginary Section of a Vortex-Ring.

Two sections of the ring would be exposed to view, as at *a* and *b*. Now, supposing the ring is moving in the direction of the great arrow, then the smoke-particles at *b* would be seen to move in the direction of the hands of a watch, and those at *a*, the contrary way.

Try now the effect of making one smoke-ring collide against another. Often they will be shattered, but under favourable conditions they will act like rings of some elastic material, bouncing and vibrating like indiarubber rings. When all the smoke is exhausted, turn the mouth of the box towards your face; a strong puff of air will be felt after each tap, showing with what energy even small compound whirlwinds force themselves along their paths.

After what we have said on the points of correspondence between whirlpools and whirlwinds, the reader will not be surprised—nay, he may even expect—to be told that there are compound whirlpools. Such is the case; and they are even more easily made than the smoke-rings we have described. Have a glass of clean water before you, and dip the handle of your pen into some milk. The drop of milk that forms at the end of it must now be brought over the water and allowed to very nearly graze its surface. When it falls, a beautiful white ring is produced in the water, which will at once travel towards the bottom. Long before the bottom is reached, however, this first-formed ring gives rise to three or four others, which in their turn produce more rings, so that there is soon quite a system of them moving in one direction. Much of what we know respecting this beautiful phenomenon is due to the researches of Mr. Deacon.

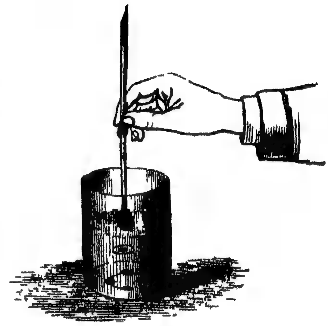


Fig. 9.—Liquid Vortex-Ring.

Thus far, then, we have seen that the whirling motion of liquids like water, and of gases like air, are the exact counterparts of each other; for whirlpools are of the same nature as whirlwinds. We have likewise seen that their ring-like combinations, such as the smoke-ring on the one hand and the milk-ring on the other, are perfectly similar. The scientific man therefore places these phenomena under one head—that of *vortex motion.*

We shall now conclude by pointing out the modern theoretical bearing of the facts the reader has become acquainted with. We may all see the Malström by taking a trip to the Loffoden Islands; but the vorticella eddy was invisible until special means were invented for magnifying small objects. Now, just as vortices exist that cannot be seen by the naked eye, so may vortices exist that the finest microscope is powerless to reveal. On this

assumption, and bearing likewise in mind the peculiar properties of vortex-rings, there are philosophers who have gone so far as to suppose that the ultimate parts of matter which chemists call atoms, are but infinitesimally small vortex-rings of a very peculiar fluid. Such is Thomson's theory of *vortex-atoms*—destined, it is thought, to play a great part in the science of the future.

# HOW ELECTRICITY IS PRODUCED.

By Lieut. Bradley A. Fiske, U.S. Navy.

THE ancients knew that if amber and jet were briskly rubbed, they would attract light bodies; but so far as our present information goes, this was all that they did know about electricity. This seems to have been the limit of knowledge for two thousand years, until Dr. Gilbert, in 1600, announced that numerous other substances could do exactly the same thing, among them such common substances as glass, sulphur, and sealing-wax. Dr. Gilbert's interesting discovery naturally attracted some little attention, and experiments were made in a small way, such as shown in Fig. 1, in which a rod of glass that has been rubbed is shown in the act of attracting a light pith ball; but soon some one found that if the ball were allowed to touch the rod, it would not only cease to be attracted, but would actually dart away from it, as if actuated by some unseen but powerful repelling force. This most remarkable performance of course occasioned great astonishment, and further experiments were made to try to unravel the secret. At length it was noticed that repulsion took place between certain rubbed bodies, even if they had not touched each other, especially in the case of two bodies of the same material, like glass, that had both been rubbed by the same substance. Further thought and experiment developed the fact that there were two opposite conditions evoked in rubbed bodies, and that two bodies which had the same condition evoked in them repelled each other, while two bodies which had opposite conditions evoked in them attracted each other. To these conditions the arbitrary names of "positive" and "negative" electricity were given.

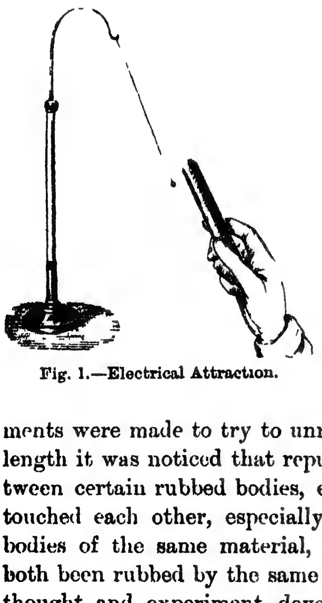


Fig. 1.—Electrical Attraction.

This led the way to the further discovery that when any two bodies were rubbed together, one had positive electricity developed in it, and the other negative. But in order to show this, it was found necessary to support one of the things rubbed on glass or sulphur or india-rubber, and this precaution was especially necessary in the case of metals. For a long while the reason was not understood, for it seemed unexplainable that if fur were rubbed on brass held in the hand, the fur alone would show signs of electricity; whereas if the brass were supported by glass or rubber, it also would be electrified. At length, however, some bright mind grasped the idea that the glass or india-rubber prevented the electricity developed on the brass from getting away; and experiments in this direction proved fully and conclusively that there were two different classes of substances—one which allowed electricity to escape, and the other which did not; and the names of "conductors" and "non-conductors" were ultimately given to these two classes. The metals belonged to the first class, and glass, india-rubber, wax, sulphur, and air to the second; while midway between stood a long array of substances like wood, paper, and cotton, which were eventually called "partial conductors."

The interest of learned men was now aroused to some extent, and the endeavour was made to get electrical effects upon a large scale. Otto Von Guericke is credited with having been the first to bring mechanical ingenuity to the production of electrical effects, he having made a machine, comprising a globe of sulphur mounted on a spindle, which was made to revolve while he pressed his hands on the rotating globe. This crude but

effective apparatus was improved by Sir Isaac Newton and others, and towards the latter end of the eighteenth century we find experimenters using large plates of glass, revolved between rubbers by means of a crank. Positive electricity was produced on the glass, and if the machine were connected to any point by a wire of conducting substance, the electricity would flow off; so that, if the supply to the wire were maintained by the revolution of the plate, a steady flow of electricity would pass along the wire. To this flow of electricity the term "current" came eventually to be applied.

We now see the learned interested in a lazy way in the study of electricity, but not taking more than a scientific concern in what seemed pretty and amusing phenomena. It appeared pleasant enough to make machines to produce electricity, but there was a great deal of exertion required to get a very small amount, and the electricity did not seem to be of any use after it had been got. One day, however, a professor named Galvani was preparing some frogs' legs for experiment before his class of students, in order to show them the curious fact that if electricity were sent through the frog's leg from an electric machine, the leg would make a convulsive kick; when, to his amazement, the frog's leg made the kick without the action or even the presence of the machine! Perplexed beyond measure, he endeavoured to reproduce this action, and finally was able to do so; and at length he found that the kick could be made to occur every time that he touched the nerve of the frog with one metal and the corresponding muscle with another, if he at the same time touched the outer ends of the two pieces of metal together. Galvani imagined that the motion was due to electricity produced in the frog's leg; but Volta, another professor, declared that the electricity was due simply to the contact of the two dissimilar metals. Eventually Volta's view was proved to be the correct one, and it soon led to important results.

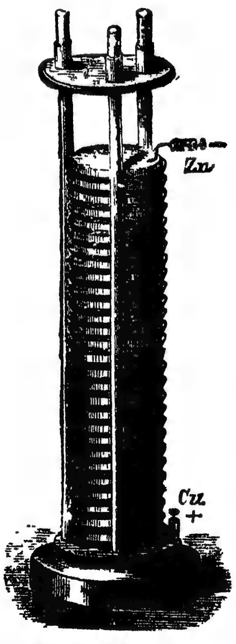


Fig. 2.—Volta's Pile.

Volta, in support of his theory, produced what was, and is still, called "Volta's pile," in which the importance and future usefulness of the new discovery were shadowed forth. The pile consisted simply, as shown in Fig. 2, of alternate pieces of zinc and copper held in contact with each other, and separated from a similar pair of metals by a piece of moist flannel or blotting-paper, which were separated in turn in the same way from another pair, there being a disc of zinc at one end of the completed pile and a disc of copper at the other end. If the two ends were connected by a wire, a continuous flow of electricity was found to pass along the wire. Volta soon invented an improvement on his pile, in which separate plates of zinc and copper, such as are shown in Fig. 3, stood in a solution of dilute acid. A very considerable flow or current of electricity was found to traverse a wire connecting the two metals outside of the liquid, and the amount and intensity of this current could be increased by the simple expedient of increasing the number and size of the vessels and the pieces of metal. This device—the jar containing two metals, zinc and copper, in dilute acid is called the simple Voltaic Cell, in honour of its inventor, and in many modified forms it is found doing useful work all over the world to-day.

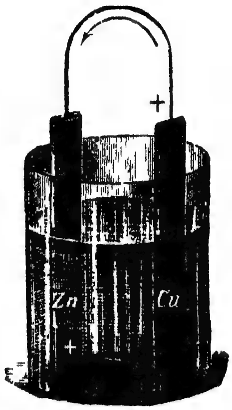
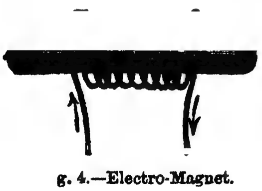


Fig. 3.—The Voltaic Cell.

The necessity for modifying and improving the simple Voltaic cell lay in the fact that, though it gave a very strong current at the first, the current rapidly decreased, and soon fell away to almost nothing. The cause of this trouble was that the current went through the cell itself (see Fig. 3) as well as the outside wire; and, in so going through, it split up the acid into its component parts—one of these parts, the hydrogen, going to the copper plate, and forming thereon a thin layer, which prevented the copper from acting in its proper capacity. The remedy, therefore, was either to prevent the formation of hydrogen on the copper, or else to absorb it as fast as formed, and prevent its accumulation. Numberless were the cells (or batteries) invented

which accomplished the object moderately well. Of these one very largely used in all countries is the Le Clanché. In this cell a rod of zinc stands in a solution of sal-ammoniac, and also standing in the liquid is a porous pot which contains a block of carbon surrounded by a considerable amount of binoxide of manganese. The carbon has been found to do just as well as copper in a cell, and the solution of sal-ammoniac is very effective in place of the more troublesome acid; while the binoxide of manganese is so rich in oxygen that it intercepts the hydrogen as it goes towards the carbon and absorbs it: that is to say, it absorbs it if the hydrogen be not generated too fast. But hydrogen is evolved by this cell rather faster than it can be absorbed, and the consequence is a gradual accumulation of hydrogen on the carbon plate, which will remain there until the battery is allowed to rest. It is because this battery requires long and frequent *rests*, that we find it used principally where the work is intermittent, not continuous.

We usually see in telegraph offices a battery called, from its inventor, the "Daniell" battery. This contains a strip of zinc in a solution of dilute acid, and a strip of copper in a porous pot, which stands in the acid, and which holds, besides the copper, a strong solution of sulphate of copper—some crystals of the sulphate being also held in a little saucer on the rod supporting the copper, so as to maintain the strength of the solution. The action of this battery is quite simple; the sulphate of copper intercepting the hydrogen in its journey to the copper plate, and absorbing it as fast as it arises; so that no matter how long or how hard the battery is worked, no hydrogen can accumulate until the battery is exhausted. Scores of other batteries are in use, but they are mostly similar in principle to either the Le Clanché or the Daniell, differing mainly in the fluid used, or details of construction, adapting them to specific purposes. Such are the Gravity, the Grove, the Bunsen, the Upward, the Schanschieff, and the chromic acid batteries, which lack of space forbids describing here.



g. 4.—Electro-Magnet.

The attention of physicists was occupied with the Voltaic battery, and with means for utilising it, for about sixty years; the most important discovery during this interval being that of Arago and of Davy, who discovered independently that if a current of electricity were sent around a bar of iron, as indicated in Fig. 4, the bar became a magnet, with a north pole at one end, and a south pole at the other end. To a magnet thus made, they gave the name "electro-magnet." The invention of the electric light and the electric engine followed, and many and very costly experiments were made in the endeavour to use Voltaic batteries to run them. In fact, the early development of the electric light was accomplished entirely by the Voltaic battery, while Jacobi propelled a boat, and Page ran a train, by electric engines, using Voltaic batteries alone. But it was soon found that the cost of getting light or motion in this way was too enormous to be commercially successful.

In 1831, however, Faraday made the historical discovery that electricity can be produced without a Voltaic battery, or the use of any chemicals whatever, by simply moving a magnet in the vicinity of a coil of wire, or by moving a coil of wire in the vicinity of a magnet. Thus, in Fig. 5, when the magnet A B is plunged into the hollow of the coil of wire, a current is produced in the wire *f f'*, and another current in the contrary direction when the magnet is withdrawn; exactly similar effects being produced if the coil is moved instead, so as to come over and cover the magnet. A discovery so simple and so significant commanded the attention of all who were interested in electricity in the remotest degree. Not only pure scientists, but practical men were attracted; for if electricity could be got simply by the relative motion of magnets and coils of wire, it could be obtained in as large quantities as desired by simply using a steam engine powerful enough to keep the apparatus in motion.


Fig. 5.

For the next thirty-nine years inventors were busy in devising apparatus for obtaining the relative motion of coils and magnets. At the end of this period a large number of machines were in use, their field being almost entirely the running of electric lights for light-houses. The best of them was probably what is now called the old Siemens machine, the principle of which is shown in Figs. 6, 7, 8. In this machine a coil of wire was wound in a longitudinal groove (*a*, Fig. 6) cut

around a soft iron cylinder, the wound cylinder (*b*) being mounted in journals, so as to be revolved

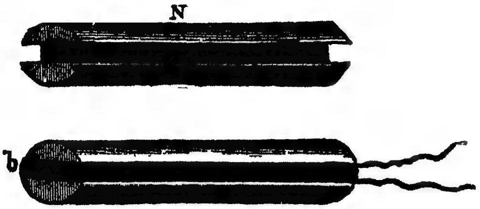



Fig 6.—Siemens Armature

rapidly between the poles of powerful magnets (Fig. 7). The principle can be better understood,

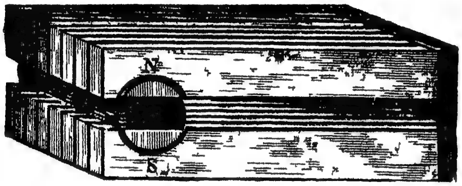



Fig 7.—Armature between Poles

perhaps, if we look at Fig 8, which shows in diagram the north and south poles (N and S) of

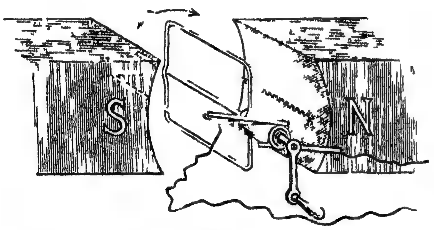



Fig 8.—Diagram of Siemens Armature

the magnets, and the coil revolving between them The ends of the coil are connected to two half sleeves on the spindle, and on these two half-sleeves press two stationary brass strips, called "brushes," which are connected to the wire of the outside circuit The movement of the coil towards and away from the magnet poles produces currents which change in direction twice each revolution—at such times as the coil ceases to approach a magnet pole and begins to recede, and *vice versâ* These alternating currents pass to the two metal half-sleeves on the spindle, thence to the brass brushes, and thence to the outside wire which feeds the electric light or engine But the current is not alternating in direction in the outside wire; it is constant, because at those instants when the current in the coil changes in direction, the half-sleeves interchange brushes, so that each brush always receives the current in the same direction Such an apparatus is called a commutator, and for obvious reasons some form of commutator, to turn all the reversing currents into one direction, is necessary in nearly all magneto electric machines.

This machine in various modified forms was largely used all over Europe, but in 1870 a Frenchman, named Gramme, made an improvement in it, so great and complete as to give a sudden and strong impulse to the rising science of electric engineering, which is still powerfully felt It will be readily understood that in the old Siemens machine, in which only a single coil revolved, no matter how fast the armature was turned, a throbbing current must have resulted Gramme conceived the idea that if, instead of one coil, he could manage to use two, four, or even a very much greater number of coils, and so arrange these coils that they would arrive at any given position at different times, he would then get a much more regular current As the outcome of his labours, he finally produced the machine shown in Fig 9, in which the single coil was replaced by a great number, which were wound separately around a ring, as shown in Fig 10, the sections being connected together all around the ring, and

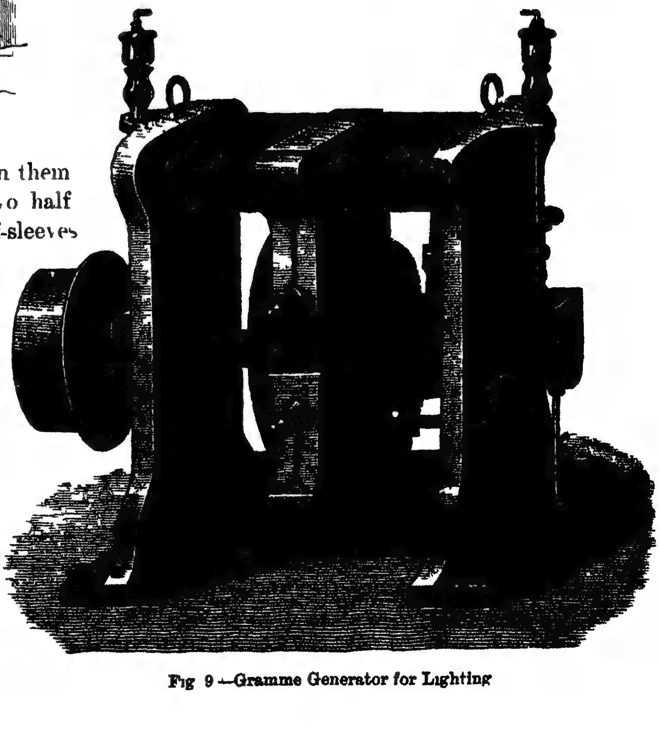
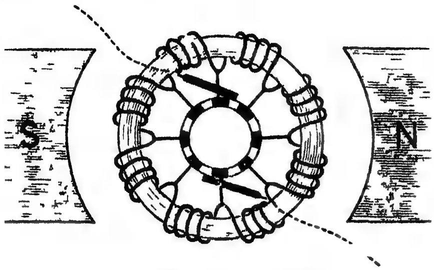


Fig 9.—Gramme Generator for Lighting

also connected to a number of narrow segments secured to the axle and pressed upon by two brushes attached to the outside wires. In this machine, as will be seen, the action of each separate




–The Gramme Ring

coil was much like that of the single coil in the Siemens machine; but as at the time when the throb produced by one coil was dying away, the throb produced by another would be increasing, the outside current was practically continuous.

The firm of Siemens and Co. were quick to note the important improvement made by Gramme, and divining the fact that the ring of Gramme had little to do with it, but was simply a contrivance to wind a great number of separate coils upon, they set to work and soon produced the machine shown in Fig. 11, called now the new Siemens machine.

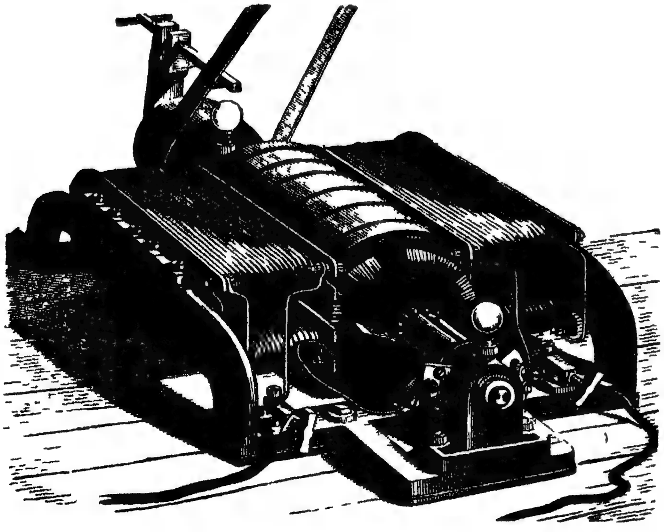


Fig. 11 —Siemens' Machine for Lighting.

In this, the multiplied coils and their connection to brass segments on the axle were virtually the same as in Gramme's machine; but they used a long drum instead of a ring to wind their coils upon, and each single coil more resembled in action that shown in Fig. 8.

All over the world we now find the Gramme and the new Siemens machines used, though in various modified forms; the modifications in most cases being so extremely slight as to be practically excuses for obtaining specific patents. Some dynamos, however, like the Brush machine, and the Thomson-Houston machine, have original points which want of space forbids our attempting to explain; these points mostly consisting in the mode of winding and connecting the coils, or the disposition of the magnets. Continuous current dynamos are almost universal in America, but in Europe is still employed another kind of machine, called the "alternating current machine," in which no attempt is made to get a continuous current, the current changing in direction, or alternating, as delivered from the coils. These alternations, however, are made to succeed each other so many times per second that the eye cannot detect them, and the light produced appears absolutely steady to the most practised observer.

Permanent magnets are seldom used in these machines, but the electric current from the machine itself is led round large field-magnets of iron, so as to convert them into electro-magnets of enormous power. There is a small amount of residual magnetism in these iron magnets, which suffices to start a small current; and this rapidly exalts the magnetism, which again exalts the current, so that in a few moments the machine is in full action, though it starts with very little magnetic power.

It will be noted that no design has been spoken of as yet by which electricity can be got from a machine, except during the time the machine is absolutely running; for it is evident that as soon as a machine stops, the relative motion of magnets and coils stops, and therefore the current stops. Many methods have presented themselves by which electricity could be utilised if the machine could be got rid of, for it is impracticable in very many places to use a steam engine and an electric machine to produce the current. For this reason electricians have been at work for years to produce something which would store up electricity and return it at once when demanded, and in 1860 Gaston Planté invented

what is sometimes called a "storage battery." In this device two plates of zinc, separated from each other, are wrapped into a cylinder, and this cylinder is put into a jar containing a liquid. The liquid is diluted acid, and we see at once a resemblance to the simple Voltaic cell; but since both plates are similar and not dissimilar metals, it produces no current. Planté found, however, that if the two plates were connected to an electrical apparatus and a current were forced through the liquid, the effect of the current on the plates was such as to cover one plate with peroxide of lead, while the other plate remained pure lead, so that they became virtually plates of dissimilar metals, and could therefore produce a current just like a Voltaic cell.

It is apparent on its face that the name "storage battery," popularly given to this battery, is improper, because nothing is stored in it. The outside current simply forms a Voltaic cell composed of a plate of peroxide of lead and a plate of pure lead standing in dilute acid; so that the scientific name of "secondary" battery is clearly preferable. The current given off by the second battery is reverse in direction to the outside or forming current, and it is observed to be accompanied by a change in the plates, both plates becoming coated with the monoxide of lead; the current ceasing as soon as the two plates become exactly similar, so that it is then necessary to re-charge the cell from an outside current. Before the cell could be made to furnish a current for more than a very short time, Planté had to charge and re-charge it a great number of times, the operation requiring several months. To hasten it, Camille Faure about 1881 conceived the idea of giving both plates a coating of red lead, which is in itself an oxide of lead, and this was found to expedite the operation considerably. A tremendous activity in secondary battery invention followed the announcement of this discovery. Great was the enthusiasm for a while, until it came to be discovered that these batteries had tremendous faults; one being that the weight of each battery was altogether out of proportion to the work it could do, and another being that the plates, if made with thick layers on the outside, so as to give a current for a long time, would crack and break up on the first opportunity and become absolutely worthless. These difficulties being, however, purely of a practical or mechanical nature, the secondary battery has been slowly but surely improving, and is gradually coming into use for a number of purposes, such as working electric engines for street cars, and running electric lights in places where it would not be convenient to run a dynamo continuously.

It cannot fail to have arrested the attention of the reader that, although the discovery of Faraday rendered possible the invention of machines which were a great improvement over Voltaic batteries, yet nevertheless the modern electric machine still necessitates tremendous loss of energy. In the first place we find that we have to burn coal in a furnace, then we have to apply the heat of the burning coal under a properly designed boiler containing water, and convert the water into steam. Then we have to lead this steam to an engine, and convert the energy of the steam into the mechanical energy of motion in the engine; then we have to connect the engine to a dynamo, and convert the mechanical energy into electrical energy. Thus we have four

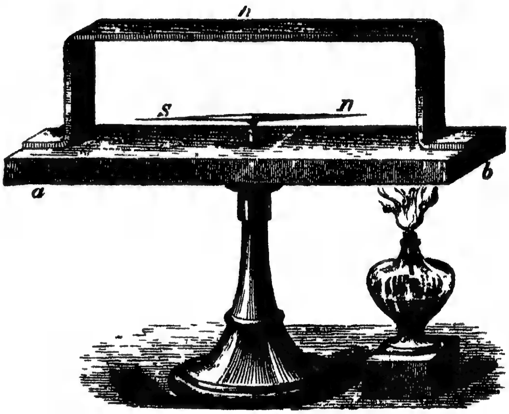


Fig. 12.—Seebeck's Apparatus

distinct operations, each one entailing great loss, so that we get only one-tenth, at the most, of the energy of the burning coal as electricity. For this reason physicists have long been trying to get electricity from heat direct. To see that this attempt is not an idle or chance attempt, let us remember that Seebeck found that if a bent piece of copper (*k*), shown in Fig. 12, be made to rest on a piece of bismuth (*a b*), and one junction of the two metals be heated, while the other is kept cool, a current of electricity will flow along the copper, as will be shown by the deflection of a magnetic needle (*s n*) placed between. Taking this as a starting-point, inventors have tried all sorts of contrivances for heating junctions between pairs of metals, but they have not as yet attained any very great success. Promising results have,

however, been obtained, the best, perhaps, being with the apparatus shown in Fig. 13. F F represent a number of iron sheets folded and fastened at both ends to large blocks of alloy, A, their outer folds projecting considerably, as shown. The inner junctions form a central flue, which is heated by a fire, and the outer ends of the iron sheets are made large, so as to radiate heat well and keep the outer

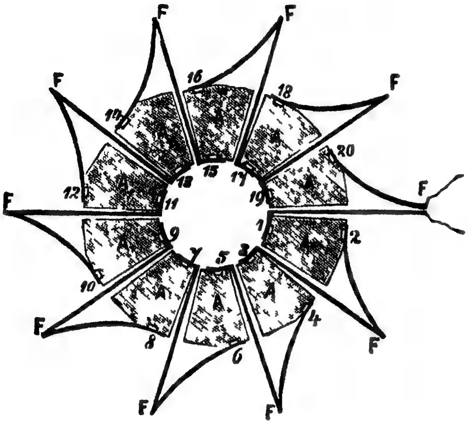



Fig. 13 —Clamond's Thermo-Pile

junctions cool. Fig. 14 represents a large number of these mounted so as to form a pile The hot products of combustion heat the inner junctions, pass up the passage T, down O and up P, and thence rise up the chimney. It is said that one of these piles has produced a current of electricity sufficient to maintain a light of considerable power.

Edison has lately announced the invention of what he calls a "Pyro-Magnetic Dynamo," which depends on the principle that iron when heated to a certain point ceases to be magnetic. Though not new in design, nor as yet efficient in operation, the fact that Mr. Edison has attacked the problem in this way, is an indication that we may at least look in this direction for interesting results. In fact, though the production of electricity by heat alone cannot be said yet to have reached a practicable point, yet progress in this direction, though slow, seems sure. Such direct production of electricity is

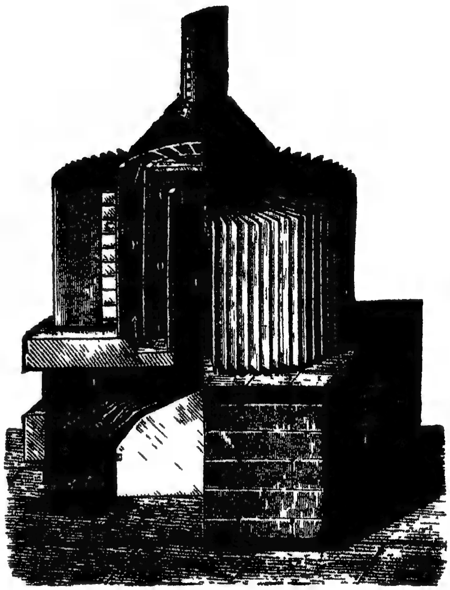


Fig 14 —Arrangement of Clamond's Pile.

the great thing now looked for by physicists in every direction, and there are a thousand men labouring to achieve it. The probabilities seem to be that it will ultimately be achieved, and the benefit to the world will be boundless in magnitude and importance.

## THE CHEMISTRY OF A BREWER'S VAT.

By W. B. Ferguson, B A, Christ Church, Oxford.

THE appearance of a brewer's fermenting-vat in full work is at the same time striking and beautiful. At the beginning of the fermentation, the whole surface is covered with a thick, light cream-coloured foam, which by degrees curls itself into wild, jagged little peaks of almost snowy whiteness, many of them twisted into the most fantastic forms. As the fermentation approaches completion, the yeast loses its uneven surface, and settles down to a fine thick, buff-coloured scum.

Now, let us try to learn as much as we can about fermentation without going too deeply into those parts of science which are unfamiliar to the general reader.

When any liquid containing grape-sugar—such as the sweet juice of fruits, the extract of malt, or a mixture of treacle and water—is left exposed to the air and undisturbed at a temperature of about 60° Fahr., it becomes turbid in the course of a few hours, and, after a short time, a scum rises to

A

the surface, a sediment falls to the bottom of the liquid, and bubbles of gas are given off, producing an appearance of boiling, from which the name fermentation (from the Latin, *ferveo*, to boil) is given to the process. These bubbles of gas continue to be given off for three or four days, or even longer, the time depending on the temperature, the composition of the liquid, and other similar circumstances. When the bubbles cease to appear, the liquid becomes clear, and is found to have lost its sweet taste, to have gained a spirituous one, and to have acquired intoxicating properties. The scum—or yeast, as it is called—which has been produced during the fermentation, when introduced into sugar-containing liquids, causes them to ferment much more rapidly than they would do if simply exposed to the air.

Such are the easily-observed facts of fermentation. Let us now examine the process more in detail. First, as to the substance which forms the scum or sediment in fermenting liquids, and is known by the general name of yeast. To the unaided eye, yeast appears to be a yellowish mud or froth; but on examining a very minute particle of yeast under a microscope of high power, we find that it consists of slightly yellowish grains floating in a clear liquid. Some of these grains float alone, others are united in branching chains of several individuals, varying slightly in size, those in the centre of the chain being generally the larger, and the average size across of the grains being about $\frac{1}{3500}$ part of an inch.

On carefully examining one of these yeast-grains—or cells, as they are more properly called—we shall find that it consists of a little bag or sac, made of the same colourless, transparent substance which forms the fibrous matter of wood (A). This bag contains a jelly-like substance known as *protoplasm* (B), and inside the jelly are one or two clear spaces (C). When the yeast-cells are examined under a microscope of high power, we see inside many of these clear spaces one or two little rounded bodies, which appear in continual motion (D).

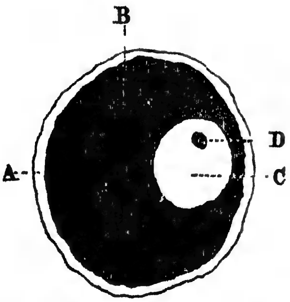


Fig. 1.—Diagram showing the Construction of a Yeast-Cell.

Fig. 1 is a diagram showing the construction of one of these yeast-cells on a large scale; while in Fig. 2 are drawings of various yeast-cells as seen with a high power of the microscope;* by adding a little solution of magenta to the yeast, the protoplasm alone will be stained, and the details thus be rendered more easily observable (Fig. 2, A.)

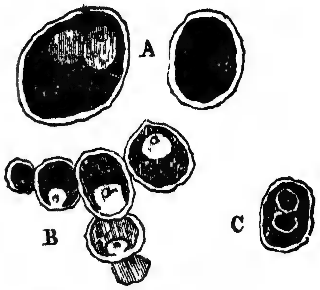


Fig. 2.—Yeast-Cells under the Microscope. (A) Single Yeast-Cells at rest, one with two Vacuoles; (B) Chain of Yeast-Cells produced by budding; (C) Yeast-Cells containing Spores.

Now, all these cells are alive, and grow, and are capable of reproducing themselves. This we may observe if we place a few yeast-cells in a few drops of an easily fermentable liquid, and continue their examination with the microscope; we find that each yeast-cell begins to give out one or two little prominences from its side; that these grow larger by degrees, and into them part of the contents of the parent cell flow, leaving an empty space or vacuole in the parent cell. These little prominences or buds when full-grown split off from the sides of the parent cell—generally, however, not before they themselves have given rise to buds, and these in turn to others (as in B, Fig. 2)—thus forming branching chains of linked cells. The original parent cell, after having given rise to several generations of buds, dies and bursts, its contents mixing with the liquid.

Multiplication by budding, as described above, takes place whenever the yeast-cells are in contact with a liquid that easily undergoes fermentation. When such is not the case, the multiplication takes place by small cells (spores) forming themselves in the interior of a yeast-cell, and being finally set free by the bursting of the sac of the parent cell (Fig. 2, C).

M. Engel gave in 1872 an account of his method of investigating this reproduction by spores. He took some fresh brewer's-yeast, and well washed it several times with distilled water, in order to take away from it all traces of fermentable liquid. The purified yeast was then spread in a thin film on a plate of plaster of Paris, which was kept well moistened with distilled water, and protected by a glass cover from the dust.

This film of yeast was examined from time to time with the microscope, and M. Engel noticed that while most of the old and full-grown yeast-cells died and broke up, the smaller ones grew larger,

* Powell and Lealand, fitted with object-glass of $\frac{1}{12}$ inch focal length.

and appeared filled with a clear jelly. In a short time, however, two, three, or four spots appeared in the midst of the contained jelly, which gradually became granulated round them, and in about twenty-four hours each of these spots had developed into a complete cell or spore, and the group of two, three, or four spores was finally set free by the bursting of the coating of the parent cell. These spores remain fixed together for some time, and when introduced into a fermentable liquid, reproduce themselves just as the original yeast did, thus proving their identity with it.

We have now learned all that mere microscopic examination can show us about the form and growth of this wonderful substance yeast. Chemists, however, tell us that yeast contains the elementary substances oxygen, hydrogen, nitrogen, carbon, phosphorus, potassium, and magnesium, and that these elements are united to form four compound substances of which the yeast-cells are composed. Now these four are :—(1) *Cellulose*—a substance similar in composition to the fibre of wood: of this the sac or cell-wall is composed; (2) *Protein*—a nitrogen, containing substance somewhat similar to the white of an egg: this is the chief constituent of the jelly or protoplasm which forms the interior of the cell; (3) *Fatty Matter*—found also in the protoplasm; (4) *Water*—existing in all parts of the cell.

Now, if a small drop of yeast the size of a pin's head be mixed with a pint of easily fermentable liquid (made by dissolving sugar and the ashes of the yeast-plant with a little ammonium tartrate in water), the transparency of the liquid will not at first be impaired by the addition; but after some hours, if kept at a warm summer temperature, the liquid will enter into active fermentation, and the few yeast-cells introduced will have given birth to myriads. Since the number of yeast-cells has been greatly increased, the quantity of the cellulose and protein which compose them must also have been greatly increased; but as the liquid itself contains no cellulose or protein, but only the mineral or inorganic substances which enter into their composition, it is plain that *the yeast-cells can manufacture protein and cellulose from mineral salts.*

Now plants alone are capable of doing this: they alone can live on mineral food; and therefore *the yeast-cell is a plant.*

We have already noticed that during the process of fermentation a gas is given off. This gas attracted observation more than three hundred years ago, when it was examined by Van Helmont, an old Dutch chemist. He found that animals could not breathe in it, neither could candles burn in it; and as it resembled in these respects the gas often found in caves, at the bottom of wells, and in other such places, he named it *gas sylvestre*—that is to say, the gas or air that is found in out-of-the-way places. Later on, it was found out that this gas was the same as that given off by heating limestone, by the breathing of animals, or by burning charcoal —in other words, the air now known as carbonic-acid gas.

The yeast-plant, then, gives off carbonic-acid gas; it is also destitute of starch; and in these two particulars it differs from the great body of plants, which, as a rule, give off oxygen and contain starch; but the class of plants known as fungi (the mushroom order), like yeast and like animals, expire carbonic acid. We see, then, that yeast is a plant nearly allied to the fungus or mushroom group.

Now, though yeast requires oxygen in order that it may live, it is by no means dependent on the air for its supply, for, as M. Pasteur has shown, if the air be excluded from the vessels in which the fermentation is taking place, the yeast, after exhausting the supply dissolved in the liquid, is able to obtain a further supply by decomposing the sugar, which is itself a compound of oxygen, hydrogen, and carbon.

In the beginning of this paper, it was stated that any sugary liquid when freely exposed to the air at a favourable temperature, would begin to ferment, and in time produce hosts of fully-developed yeast-cells. The question then arises, Where do these yeast-cells come from? And to this question only two answers are possible—either they have been generated in the liquid, or have been introduced from without. The first of these two hypotheses—that of the "spontaneous generation" of ferments—was in former times accepted as the correct one; but a consideration of the following experiments will convince the reader that the second hypothesis is the more probable of the two.

In the first place, it has been found that the life of the yeast-plant is destroyed by heating it to the temperature of boiling water. Three glass flasks, each partly filled with an easily fermentable liquid, are heated to the boiling-point. The neck of the first is drawn out and hermetically sealed before the blowpipe, while the steam is still issuing from it, thus effectually precluding the contents from contact with the air; the neck of the second flask is plugged tightly with cotton-wool; while the neck of the third flask is left entirely open. The three flasks, being now allowed to cool down to

between 77° and 95° Fahr., the temperature most favourable to fermentation, are carefully examined with a microscope from day to day. In a short time the liquid in number three will enter into active fermentation, becoming turbid, giving off carbonic-acid gas, and forming a scum of yeast-cells; while the contents of number one and number two will remain quite clear and free from fermentation.

We see, then, that sugary solutions eminently fitted to support the growth of the yeast-plant, will not enter into fermentation if excluded from the air, or if exposed to air filtered through a tight plug of cotton-wool, provided all existing yeast-cells in these solutions have been previously destroyed by submitting the liquid to a boiling-heat; and, secondly, we observe that such solutions, though at first containing no yeast-cells, yet when freely exposed to unfiltered air develop hundreds of such cells, and enter into active fermentation, thus proving that the so-called spontaneous fermentation of saccharine liquids is due to the introduction of yeast-cells, or spores, which are floating about as fine dust in the air, and are capable of being separated from the air by filtration through a plug of cotton-wool. Pasteur has shown that these air-carried yeast-cells may also be destroyed by passing the air through a red-hot metal tube, such air having no power of causing sugary liquids to ferment.

After having thus shortly considered the life of the yeast-plant, let us now see what are the chemical and physical changes which are brought about during fermentation by the growth of this yeast-plant.

It has long been known that all liquids capable of undergoing ordinary or alcoholic fermentation must contain sugar in some form or other, and also that the chief result of the fermentation was the changing of the great bulk of this sugar into alcohol, or spirit of wine, and carbonic-acid gas. An experiment arranged in the following way is well

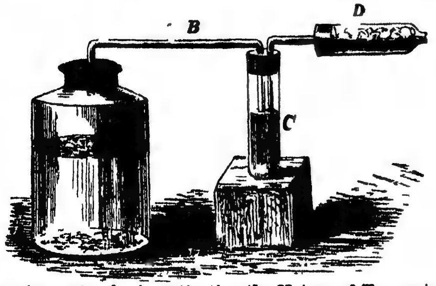



**Fig. 3.—Apparatus for investigating the Nature of Fermentation.**

adapted for showing this. Let a wide-mouthed bottle A (Fig. 3), holding about a quart, be half-filled with a solution consisting of sugar and water, with a little yeast-ash and a small quantity of ammonium tartrate. In the neck of the bottle fix a cork, through which passes the tube B, the other end of which goes down to the bottom of the test-tube C, which contains a solution of baryta water; from the cork of C passes a short tube, ending in the wider one D, which contains a few pieces of caustic soda, intended to prevent all traces of carbonic acid which may be in the air passing back into the baryta water contained in C.

On adding a small quantity of yeast to the solution in A, and keeping the apparatus in a warm room, the liquid will soon become turbid and begin to ferment, giving off bubbles of gas; these, passing into the baryta water in C, will produce a dense white precipitate of barium carbonate, which may be filtered off and afterwards examined. On the addition of hydrochloric acid, it will give off carbonic-acid gas, which may be recognised by its property of extinguishing flame and giving a white precipitate or sediment with lime-water.

During the fermentation, a thermometer placed in the liquid will show that its temperature is higher than that of the surrounding atmosphere, this heat being due to the combination of the carbon of the sugar with oxygen to form carbonic acid—the process being, in fact, a slow burning, just as charcoal-burning in air is a quick burning, the heat in both cases being due to the same cause.

After the fermentation is over, the liquid may be filtered from the scum and sediment of yeast, and distilled until about one-quarter of it has passed over into the receiver. This distillate still contains water, from which it should be freed by being poured over some lumps of quicklime placed in a large retort, allowed to stand for twenty-four hours, and re-distilled. The second distillate will be pure alcohol or spirit of wine, and may be recognised as such by its taste, smell, inflammability, and other well-known characteristics.

In addition to these chief products—alcohol and carbonic-acid gas—small quantities of two other ones are uniformly produced: one a somewhat rare one, called succinic acid, and the other a very common one—glycerine. And some very intricate experiments made by M. Pasteur have led him to the conclusion that out of every hundred parts by weight of sugar which enter into the fermentation, ninety-five parts suffer decomposition into alcohol and carbonic acid, four parts go to the formation of succinic acid and glycerine, while one part disappears, having served as nourishment for the yeast-plant during its growth.

We have now seen that fermentation consists in two actions, which go on at the same time—viz., the growth of the yeast-plant, and the splitting up of the sugar into alcohol and carbonic acid, together with small quantities of succinic acid and glycerine; and since the first of these never occurs without the second, we are led to the conclusion that the splitting up of the sugar in this remarkable way is the result of the growth and reproduction of the yeast-plant.

We do not as yet know what is the precise manner in which the yeast-plant effects these changes. All that we can say with certainty on the subject is that the chemical act of fermentation is essentially a correlative of the vital act, beginning and ending with it.

In addition to the ordinary or alcoholic fermentation described above, the reader will do well to remember that there are others—the "acetic," "butyric," and "lactic," for instance—in each of which peculiar changes are brought about by certain living vegetable organisms.

Very soon after the discovery that the so-called spontaneous fermentations arose in most cases from the fermentable liquids being infected by ferment-germs which were floating about in the air, the idea suggested itself to many chemists and physicians that certain classes of contagious diseases were very probably communicated in a similar manner; and it is believed by many that all diseases contagious by inoculation, or more or less direct contact, are produced by fermentations of the liquids contained within the body, set up by foreign bodies of an organised nature similar to ordinary ferment-germs.

It has since been shown without the least doubt that certain malignant carbuncles are really the result of the fermentation of the fluids of the body, which fermentation is carried on by the growth, reproduction, and decay of microscopic but easily recognised organisms; and just as it is the solid cells only of yeast which are capable of exciting alcoholic fermentation, so in cow-pock, glanders, sheep-pox, and other infectious diseases of animals, the solid portions of the virus are those by which alone the disease is communicated. Further experiments are, however, needed before this germ theory of contagious diseases can be considered as completely established.

We may conclude this paper with a brief summary of the knowledge we have gained by this short study of the process of fermentation as seen in a brewer's vat.

We have learned that fermentation consists in the formation from sugar of alcohol, carbonic acid, and small quantities of glycerine and succinic acid; that this series of transformations is brought about in some manner by the growth, reproduction, and death of the yeast-plant in the fermenting liquid.

Of the yeast-plant itself, we know that it is a simple cell—a bag of cellulose containing a mass of jelly or protoplasm, in which are one or two clear spaces; that this cell can either reproduce itself by budding, or by spores; and that the yeast-plant, from the fact of its breathing out carbonic-acid gas. is closely connected with the group of fungi or mushroom-like plants.

We have learned that yeast-cells are floating about in the air, from which they may be removed by efficient filtration, or destroyed by heat, and that they are ready to begin reproduction and set up fermentation as soon as ever they come in contact with a suitable liquid.

We see further that by considering this subject of ferment-germs, physicians have been led to the conclusion that many diseases are really a kind of fermentation of the animal fluids, and may be conveyed by disease-germs.

Finally, some of our experiments seem to show the impossibility of the "spontaneous generation" of ferments in liquids not previously containing them; but the question of the spontaneous generation of living organisms, whether animal or vegetable, although very improbable, is one on which certainly "doctors differ," and the scientific world has not as yet come to any general conclusion.

# A PIECE OF SPONGE.

By J. Murie, M.D., LL.D., F.L.S., etc.

FAMILIAR as is an ordinary piece of sponge, yet few people are able to give any rational account of what in reality it is. The dictionary definition, "a soft, porous substance, remarkable for sucking up water," hints only at one of its qualities, common to a number of objects; as, for example, a piece of blotting-paper, which to some extent is equally bibulous. Even to the minds of most well-educated persons the true nature of the substance is far from clear. The common and current notion that sponges are marine plants, or in some way or other appertain to the sea-weed group, would seem to have its foundation in the general aspect of the objects themselves: their light, fibrous, vegetable-like texture, the well-known fact that they are procured from the sea-bottom; and as occasionally they are exhibited in museums and shop-windows attached—stalked or rooted—to a portion of rock or other substance, it is easy to understand how they come to be looked on as plants. Nor is this to be wondered at, seeing that, even up till within a few years back, naturalists, and those who had made a special study of the sponge tribe, were by no means agreed as to their nature. Some would have them to be plants, others that they were animals of a low order, and so they were bandied about in the systems of classification, at one time finding a place in the animal, at another in the vegetable, kingdom. Nay, more—at length a learned German hit upon the plan of placing them, along with several other lowly organisms of equally uncertain nature, in a separate group intermediate between plants and animals. Thus one would suppose the perplexity of the case got rid of; but not so—"confusion" became "worse confounded," until imagination has run riot on the subject of some phases of their development; and, once fallen into the hands of theorists, poor sponge has been made the basis of a history and plan of creation.

Let us place before us an ordinary bit of sponge taken from the dressing-table, or purchased out of the basket of the street hawker. Perhaps the coarser the specimen is, the better will it be for our purpose—that, namely, of examining and illustrating its structural peculiarities.

The physical properties of such a piece of sponge are few, but manifest and characteristic. We observe that its colour varies from pale amber to a deep, occasionally ruddy, brown. Bleached specimens are, indeed, sometimes hawked about our streets; and in Paris, I am told, sponges deprived of much of their natural colour by chemical means* are in vogue.

The best varieties of Turkey sponge, as is well known, are soft and velvety to touch. Squeeze one, and it shrinks in dimension; the grasp unloosed, it springs back to its original form: it is thus resilient and elastic to a degree. Its lightness is a most appreciable quality. A morsel placed on the tongue yields no distinct taste; chewed or pressed between the teeth, according to the sort of sponge does it seem fibrous, or stringy, or coarse and gritty from the sand and foreign particles retained within it. Cast it into water; at first it floats freely, but by degrees absorbs the fluid, settles down, and ultimately sinks. It is thus remarkably "porous" and absorbent, and, as the phrase runs, "is porous as a sponge." As a body, nevertheless, it is opaque, though thin slices transmit light, like shavings of horn, while a flood of light passes through the openings and vacant spaces, whatsoever be the direction of the cut. Apply flame to a small portion. It does not burn brightly, but frizzles, singes, or chars, according to the intensity of the heat. If this is great, a pellicle of metallic lustre, or light fragment of charcoal-like matter, is left. Meantime there arises from it a strong, disagreeable odour, very similar to that produced by the imperfect burning of hair. Neither cold nor boiling water, alcohol, ether, ammonia, nor, indeed, most chemical reagents, reduce sponge-fibre to a soluble consistence; even the strongest acids and alkalis act upon it only slowly, so that in this respect it is a very resistant body.

As regards its own chemical composition, analysis shows that silk and sponge scarcely differ in composition. A peculiar substance called "fibroin" enters largely into the constitution of the sponge of commerce. Neither this substance, nor anything in the slightest degree resembling it, is found in any plant.

We thus learn that sponge, in its physical properties alone, might be of a fibrous, vegetable nature, but chemically it exhibits phenomena and

* By the use of hydrochloric acid, and hyposulphite of soda.

composition akin to what are attributed to belong to animal bodies.

In its mechanical construction, an examination of the specimen before us shows that the sponge combines the maximum of lightness, delicacy, and strength, with an architecture wonderfully adapted to fulfil a combination of purposes.

The much-vaunted skill, handicraft, and genius of our engineers may here take a lesson from mother Nature in one of her humblest efforts.

Under the microscope a thin slice of the sponge consists alone of a meshwork of yellowish, solid,

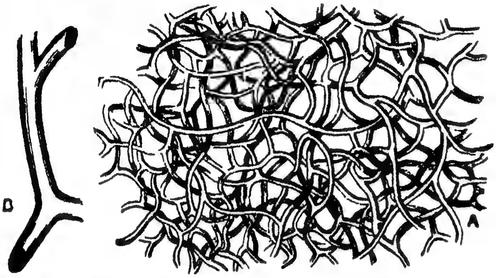



Fig. 1.—(A) Microscopic Appearance of Sponge-Fibre; (B) a Fibre, showing its solid Structure, greatly magnified.

interlacing filaments or threads. These are exceedingly delicate in some examples of the best Turkey sponge, averaging $\frac{1}{900}$ of an inch in diameter, but in others are much coarser, and of a greater calibre. Usually they are almost uniform in thickness, though sometimes, as Professor Quekett first observed, a fibre double the size of the rest is met with. These bigger fibres possess great interest, for they not unfrequently contain rudiments of minute flinty, needle-shaped bodies, termed *spicules*. With the exception mentioned, these flinty needles are absent in the sponges of commerce; but these bodies—of most extraordinarily varied figure and size—nevertheless, play an important part in the economy of some sponges.

For tenuity, elegance, and relative strength, a spider's-web is a marvel; and hardly less wonderful for length of fibre, lightness, and close packing, is the cocoon of the silkworm. Combine the material and principles of these two, and there results the netted, throughout permeable, water-sucking object —our common toilet-sponge.

The further building up of the loose network of fibres is not a matter of mere indifference, for although in sponges there is an almost endless variety of patterns, both as to their exterior and interior conformation, yet all are formed so as to permit the passage of water in certain directions.

In the finest sorts of cup-shaped sponges the hollowed top is drilled with great-sized holes, which chiefly lead directly downwards. On the other

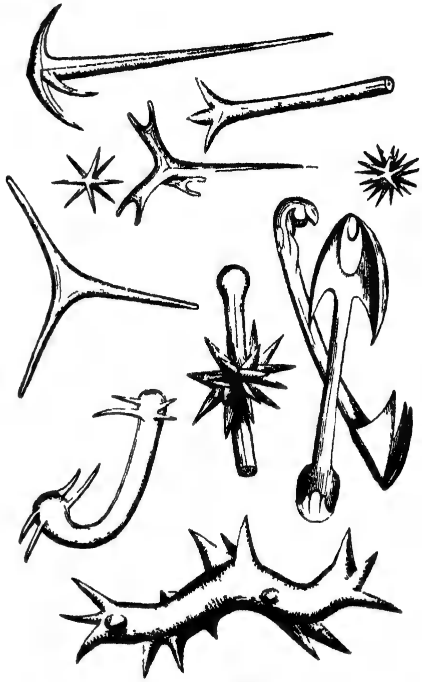


Fig. 2.—Various Forms of Sponge-Spicules, highly magnified.

hand, the outside of the cup is perforated by openings like so many pin-holes (A, Fig. 3), and

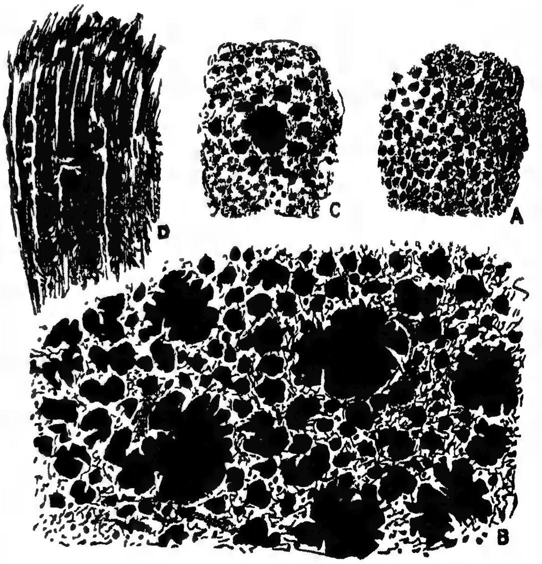



Fig. 3.—Outer Surface of Sponges of different Sorts, all natural Size. (A) Cup-shaped Variety; (B) Honeycomb Sponge; (C) Toilet Sponge; (D) Bahama Sponge, partly in Sections, showing projecting Extremities and internal tubular Character.

these more often lead obliquely down and inwards. But the general uniformity of these latter, and as

contrasted with the large orifices placed at the top, is a point of some importance.

In the bath or honeycomb sponge of trade, the dome-shaped expanse is not only rougher than in the "cup," but what gives rise to the technical name is the honeycomb-like dispersion, throughout the entire surface, of large gaping apertures (B, Fig. 3). Around and everywhere between these is a still more numerous series of pinhead-sized orifices, whilst the intervening finely reticular web forms the body of the sustaining tissue. In this sort of sponge is also well seen a peculiarity less apparent in the finer "cups." Long, jagged peaks of the felt substance stand out at all points, and they particularly surround the large apertures, even forming a crater-like rim, bending over or partially obscuring the

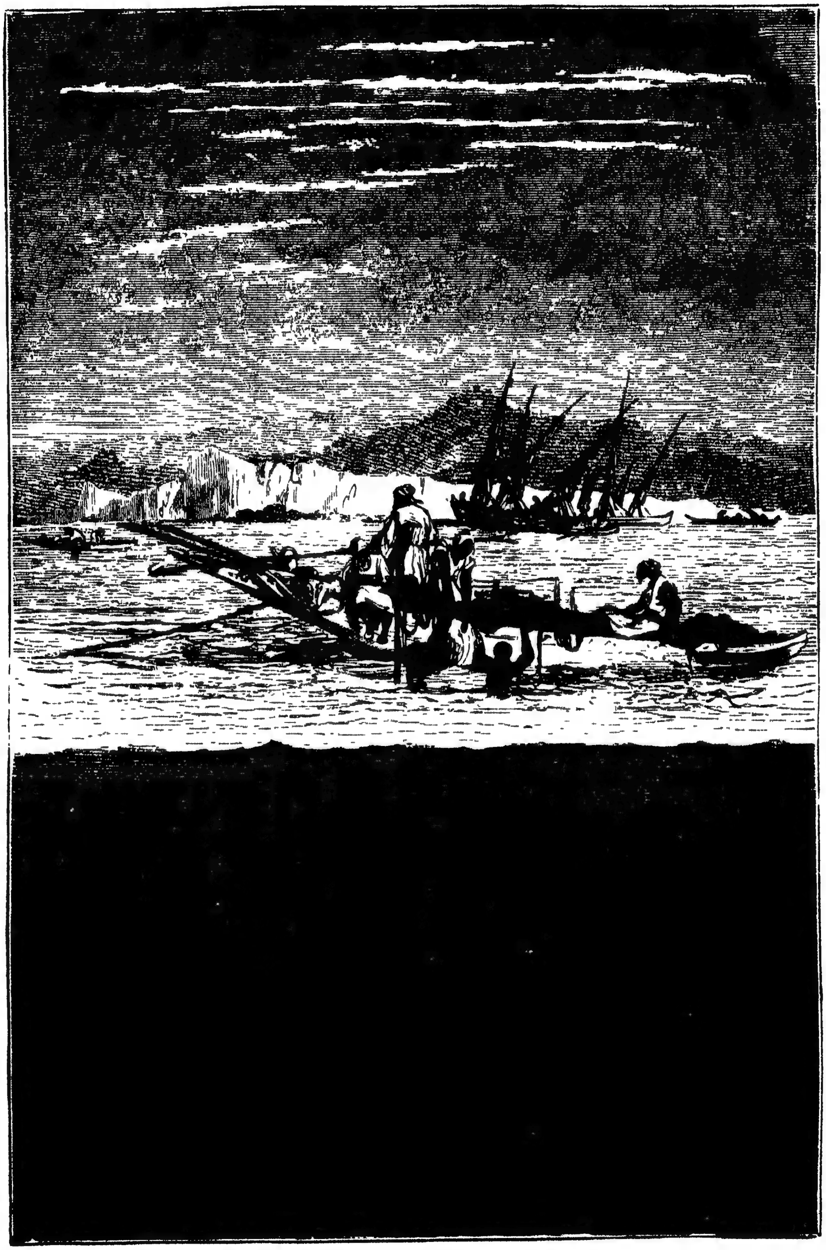


Fig. 4.—Syrian Sponge-Fishers at Work.

hole. In some of the nodular or spread-out toilet-sponges, again, a modification is met with. In shallow hollows, or occasionally on elevations, here and there a big hole is immediately encompassed with a number of somewhat smaller-sized subsidiary ones (C, Fig. 3), producing thereby a star-shaped appearance.

In the inferior sorts of sponges, "Bahamas" to wit, the fibre is not only coarser, bristly, and brittle, but the wide channels run up in vertical parallel columns; the fibre shooting forth in unusual, long, free extremities of a tubular or a pencil or brush-like character (D, Fig. 3).

From what we have thus learned regarding the structure of the sponge before us, we can now understand how a dry sponge so greedily sucks up water, and so readily parts with it on pressure. Passages everywhere communicating, whose walls are made up of a close network of the finest fibre, permit and cause the fluid to rise by the "capillary attraction" of the physicist, until the substance is perfectly saturated; capillary attraction, as Faraday has well put it, being "that kind of action or attraction which makes two things that don't dissolve in each other still hold together;" and, indeed, where the interstices are extremely narrow, the fluid is forced on by the weight of the mass behind. The currents of water in the live sponge, though, proceed from a different cause. Again, the minuteness, flexibility, toughness, and withal durability, of the tissue, together produce those qualities for which the sponge-substance is valuable and becomes an every-day necessity.

But hitherto the dried sponge, which after all is only the skeleton, has engaged our attention. The living object and its economy carry with them life-problems of exceeding interest—an epitome of all those functions performed by the complicated organs in our own body, but here reduced to the utmost simplicity. Other generalisations, moreover, hang thereby.

To see the sponge in life we must now go to an aquarium, or seek for some shady rock-pool on the coast where specimens of our smaller native sponges cover the stones, or cling to the roots in the tangle. It would still be better could we examine one from the "fishing-grounds" in the Mediterranean.

Incidentally it may here be mentioned that in collecting living sponges in the East, a fleet of one-masted, lug-sailed boats (*caiques*), manned by crew and divers, are occupied during the whole of the summer months. The Syrian diver goes down naked, with an open net around the waist, and carries a stone attached to a rope. Without instruments, he tears the sponges from the rocks, throws them into the net, and giving the signal, is hauled up (Fig. 4).

The Greek divers, among their own islands or on the African coast, use a diving-dress and knife or spear to cut away the sponges from their attachment; but as the air-tube often fouls, they will throw this aside. The men remain down from 1 to $1\frac{1}{2}$ minutes. They descend to the depth of 8 to 12 fathoms, but expert divers will go down even 40 fathoms. Usually, from a dozen to thirty sponges reward a plunge. The best kinds are said to flourish in the deep water; but this is more likely to be from being less disturbed and picked off. Certain London merchants now buy direct from the boats, prepare them by drying, &c., and simply pack in cases for transmission. A fishing-village is often strewn with sponges lying out to dry, giving the neighbourhood a strange but characteristic appearance.

When first obtained from the sea, the sponge of commerce is a vastly different thing from those in our shops. It then is comparatively heavy, and presents a filthy, dirty, slimy appearance, with an odour of shell-fish. Few holes are visible, most seemingly being blocked up with the glutinous substance. Then the process of what technically is called "taking the milk out" is proceeded with, prior to sun-drying: for if the soft matter be left in, putrefaction results. The process adopted by some of our English merchants is secret, and the precise means in use among the fishers is not clearly understood except by the initiated. At all events, a squeeze and a wrench, or stamping under foot, extract a milky or semi-transparent, sticky, gelatinous substance. The sand and grit in the new-dried sponge are foreign residue, either partially subservient to preparation, or surreptitiously introduced to add weight and increase the money-value of the article as sold by weight.

The slimy substance or fleshy material above-mentioned is the soft part of the living animal—or congeries of animals, for such they prove to be. This jelly—so delicate that it runs off like milk from the fibrous skeleton when death has occurred, or occasionally dries like glue on the fibre—everywhere lines the fibrous structure, and forms a surrounding film. In appearance and composition, it is much the same as the white of egg. For long, its nature was held to be problematical, even among the master-minds of zoologists, and all experiments and opinions elicited nothing more than its being a torpid mass of doubtful vitality

But, after the labours of a host of scientific investigators, its animality, and many other strange particulars are now proved beyond a doubt. Examine attentively, say, a sponge in the aquarium. When under favourable circumstances for observation, the following particulars may be verified.

First, then, currents of water run in through the *small* pores (Fig. 6), and traversing throughout the

Fig. 5.—Piece of Sponge showing the outgoing Water-Currents.

sponge-material, at length return and make their exit in streams through the *large* holes (Figs. 5 and 6). In sponges growing near low-water mark, as the tide recedes, all the orifices close, again to open and admit the water as this rises and covers the object. This fact can be witnessed in the sponges on our own rocky shores, and if a small living piece is put under the microscope in a watch glass, with sea-water to which is added a little carmine, the currents of particles are most convincing. To the living sponge it matters not whether the surrounding water is perfectly still or in movement, the currents of water permeating its substance continue all the same.

The majority of naturalists agree that the water-currents are due to "ciliary motion." This vital action is the same which drives upwards the phlegm or irritating particles from our own lungs and throat, and which also sends whirling about to and fro the young oyster, before it has settled down to its sedentary shelly existence. Besides, ciliary action subserves many other purposes throughout the animal economy. "Cilia" (their name being derived from the Latin for eyelash) are hair-like filaments or threads of extreme tenuity (no more than $\frac{1}{4000}$ to $\frac{1}{8000}$ of an inch in length), which keep undulating like a field of corn blown by the wind. They thus set up a current, or push along the fluid or other movable particles on the surface, in a uniform given direction. The cilia, however, in the sponge are not promiscuously dispersed, but are confined to minute, deeply-situated chambers or dilatations of the canals (Fig. 6). Giving ourselves no concern with technical terms other than regarding them as "ciliary chambers," we

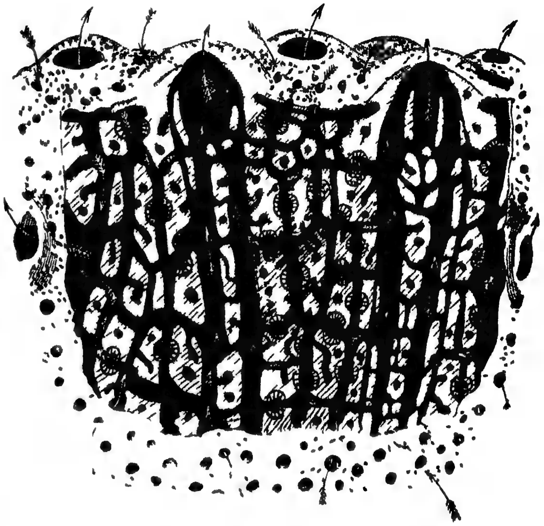


Fig. 6.—Diagram of interior Sponge-Channels, and Water-Currents following Direction of Arrows, with here and there Ciliary Chambers.

nevertheless find they possess considerable interest. These chambers, of very diminutive capacity, are encircled with a closely-set series of flask-shaped cells or "bladders," sunk in the gelatinous, fleshy substance, a single lash-like cilium protruding from each (Fig. 7). In this respect there is analogy to the cilia in our own frame, which are attached to little scale like bodies (scurf being scales of this nature, but without cilia), in some cases often thrown off and as quickly renewed.

But these flask shaped cells of the sponge are in reality so many microscopical animals, each endowed with a vitality of its own, and in structure precisely identical with some of the singular free-moving animalcules of our ponds and ditches; so that the sponge in a certain sense is a colony of individuals aggregated and held together by the white-of-egg-like substance, and, where present, fibre or *spicules*, the flints or needles.

Arranged in the bow-shaped recesses, like bottles in a bin (A, Fig. 7), these sponge-cells or monads freely ply their cilia, and hence comes it that the sea-water is drawn through the porous substance. That it only enters at the small holes and issues at the big ones is dependent on the special direction

given by the moving cilia. It possibly may also be that by alone entering the minute pores the chances of the passages becoming blocked up is reduced to

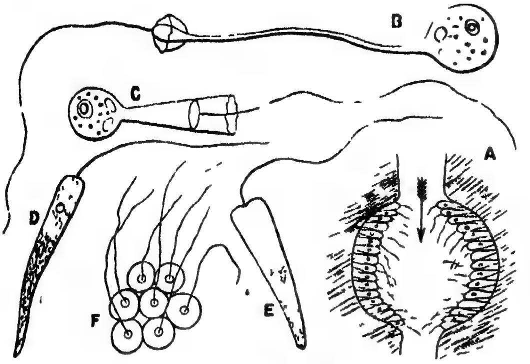



Fig. 7.—(A) Diagram of Ciliary Chamber, and (B to F) Sponge Animalcules or ciliated Cells from different Species of Sponges. All highly magnified.

the minimum. But withal, strange—even living—objects do betimes get drawn in and entangled, queer pranks arising thereby.

Reviewing now what we have learned from the bit of sponge before us, we find, viewing our facts in their simplest aspect, that a sponge may be compared to a fibro-gelatinous colander, grosser particles being retained and absorbed as nutriment, the passing fluid carrying off waste material, &c. Professor Huxley, often as happy in simile as pungent in repartee, compares the sponge to "a kind of subaqueous city, where the people are arranged about the streets and roads in such a manner, that each can easily appropriate his food from the water as it passes along."

Both as a mechanical and physiological apparatus, sponge simplicity contrasts with the complications involved among the higher animals. Of blood there is none, neither intricate mechanism of heart, arteries, and suchlike; still, the function of circulation is effectually performed, and nourishment-bearing fluid —water—brought into proximity with every part of the frame. Lungs, gills, &c., are dispensed with, yet the equivalent of respiration takes place by the constant renewal of the sea-water; for oxygen is absorbed, and carbonic acid given off. Then, as to the function of secretion, and the excretion or giving off of waste products: skin, with its sweat-glands and other accessories, and kidneys, &c., to boot, are not brought into requisition, yet much refuse is eliminated. During the digestion and the absorption into the general structure of its food, a solvent is poured out, and yet there is no stomach, gut, or glands. The food-particles come haphazard with the current, and here and there get entangled among the jelly body-substance, which imbibes such minute molecules as may be solvent in the slimy fluid, and allows the others to pass on. It may here be asked—is there any nervous influence guiding and controlling selection of the atoms, acting on the general contraction of the slimy flesh or movement of cilia, &c.? None whatsoever! At least, no trace of anything approaching nervous elements has hitherto been discovered, under the highest powers of our microscopes, and other means of research.

It remains still for something to be said concerning reproduction, growth, and development, to complete the life-history of a sponge. Herein lies a wide field for generalisation and speculation. Accordingly, those naturalists gifted with the powers of imagination have constructed a system of animal transformation which sets Swift's satire on the labours of the professors in the Lagado Academy of Projectors completely in the shade.

It is a matter of every-day knowledge that plants may be propagated by cuttings, by grafting, by buds, by bulbs, or by seeds. Now, among the lowest forms of animals, the sponges included, processes of reproduction analogous to those of vegetables are not of unfrequent occurrence. Unfortunately, a complete history of the development of the common sponge (*Spongia officinalis*) has not yet been followed out in detail; but a study of other forms, in many respects, enables a fair idea of what in the main is prevalent among the group to be considered applicable to it.

There is a kind of sponge which grows in the fresh water, and is to be found, among other places throughout the country, on the floating timber in the Commercial Docks at Rotherhithe, at Cookham on the Thames, and in some of the canals in the neighbourhood of London. The living sponge, therefore, can easily be obtained and examined by any one desirous of making himself practically acquainted with the water-circulation, development, &c. In this, the river sponge (*Spongilla fluviatilis*), there is no network of horny fibre, but, instead, a meshwork of the needle-shaped *spicules*. For our illustrations of propagation this does not negative the general conclusions.

If a mass of this be torn asunder or cut in pieces or, as occasionally happens, spontaneously divide, each of the parts will maintain its independent existence, and flourish as a separate individual or specimen. This would be equivalent to the "cuttings" of plants, though it implies something more. Again, two *spongillæ* growing apart may approach,

and when brought into contact will fuse into one, so that afterwards no line of demarcation can be distinguished. This to a certain extent represents the operation of "grafting," as practised by horticulturists; though, in the case of the sponge, fusion of substance is so complete that they may be truly regarded as a unit, whereas plants grafted still retain their specific peculiarities apart from the stock whereon united. Still further, various sponges may send forth a process or body comparable to a bud, which, when thrown off, lives, grows, and ultimately propagates its kind, as would a plant under similar circumstances. But there is another modified process

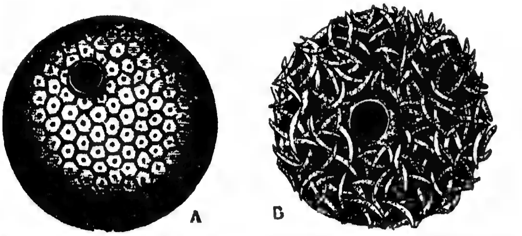



Fig 8.—Winter-bud or Gemmule of *Spongilla* (A), in natural Condition, and (B) prepared with Nitric Acid to show its Spicular Coat. Both highly magnified, as seen under the Microscope

akin to this, which takes place by a kind of winter-bud, to all intents and purposes representing propagation in plants by bulbs. In this, towards the autumn months, a number of the sponge-particles seem to fuse together and form a horny or flinty shell (Fig. 8), of a round, oval, or occasionally elongated shape, but with an opening, and containing within a number of seed-like bodies. These remain quite inactive through the winter; the spongilla itself meantime having died down. As spring comes round, however, the seed-like bodies, heretofore dormant, manifest vitality, and each, issuing from the shell by the opening, commences life as a separate and free-moving individual; ultimately settling down, growing, and becoming sponges similar to that from which they have been produced.

The foregoing phases of reproduction are regarded as modifications of budding; but there is still another mode, where eggs are hatched within the body of the parent.

In this case certain of the marine sponges, about midsummer, develope in their interior a multitude of little cells or bladder-shaped structures—the eggs—which are either scattered throughout the tissue or aggregated in heaps within a sac (1, Fig. 9). These ova, though so minute and transparent, resemble in most particulars a hen's egg; for, although destitute of a calcareous shell, they nevertheless have a substance corresponding to the yolk, another to the white or albumen, and a delicate membrane

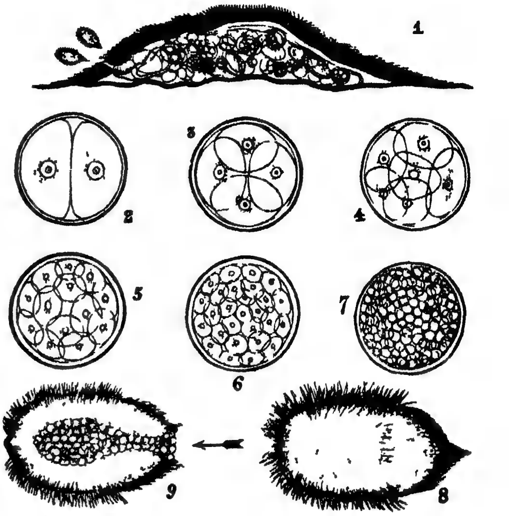



Fig 9.—Sponge Eggs in Stages of Development, from their Issue until becoming a free-moving, ciliated Larva—the Arrow denoting Direction propelled. Highly magnified. Modified after Carter.

surrounding this. Moreover, a process identical with what occurs in the hatching of a hen's egg takes place. This process goes by the appellation

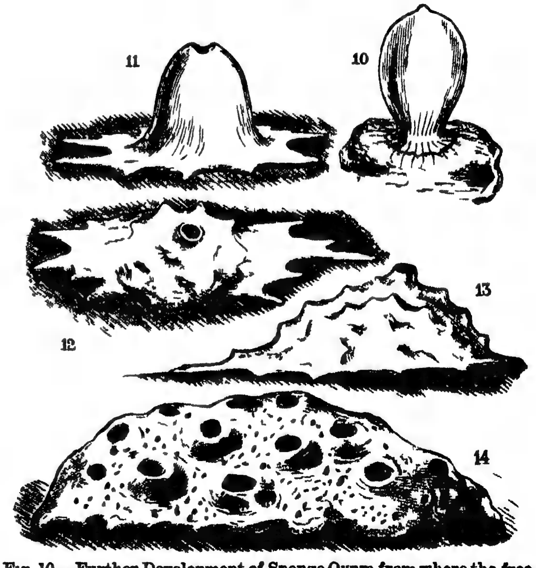



Fig. 10.—Further Development of Sponge Ovum from where the free-moving Larva settles down until it assumes the Structural Peculiarities of a true Sponge. Modified after Carter.

of segmentation or cleavage of the yolk. The germinal point, as in the hen's egg, sets up an action in the yolk-substance, and a division into two cells with central points results. These cells, or little spheres, again, divide into four; at a further stage,

subdivide into eight; still again subdividing, until at length the yolk appears under the microscope as a confused mass of aggregated cells (compare 2 to 7 in Fig. 9). The egg, now increasing in size, assumes an oval figure, gets an outer hairy-like covering of cilia of extreme tenuity, and these by their lashing movement drive the larval sponge freely about the water. Later on, an inner growth of cells arises, and some, notably, are produced at the one end, the opposite end of the larva being provided with a nipple-shaped process (8 and 9, Fig. 9). Thus transformed, the larval sac settles down and fastens itself by the root-cells to pebble or rock, as the case may be; and the cilia are then lost. The fixed embryo hereafter increases in bulk, begins to spread out a gelatinous substance at its root, and the free conical end shows a depression. Then, as growth proceeds, the latter becomes a hole—one of the future exits of water-currents—whilst smaller-sized pores of ingress become faintly visible. The true sponge character now becomes manifest, perforations proceed apace, and the structural organisation already referred to ultimately gives completeness to the compound animality of the sponge (compare 10 to 14, Fig. 10).

Such are the changes undergone from egg to adult in certain of the sponge tribe. This group, as a whole, with a structure and life-history comparatively simple in its kind, withal possesses, as has been shown, a many-phased mode of development, combining that supposed more truly to belong to plants as well as that of the egg of animals even of higher grade. The changes undergone from egg to larval stage, indeed, often impart such resemblances to those of animals high in the scale of being, that it is this transformation that has led to the assumption, and forms the basis, of those who hold to the theory of a progressive development and intimate connection between the lower and higher animals.

Let us set aside, for the moment, the scientific aspect of the nature, &c., of sponge, and discuss the subject from its commercial point of view. We then find that the domestic uses of sponges create a trade in this country alone estimated at an annual value of from £150,000 to £160,000. The British import trade, I learn from one practically acquainted with it, is in the hands of seven or eight firms. These houses, roughly speaking, altogether receive yearly from abroad somewhere about 460 tons weight of sponges of various sorts. There being no duty on sponges, they arrive in this country without let or hindrance from Custom House officials; consequently we can give only approximately the number and total value of those imported. The sponges of commerce are derived from the Mediterranean and the West Indian Seas. The former go under the name of "Turkey" sponges, and are those in chief use in this country.

The best kinds of the so-called "Turkey" sponges are said to be obtained at Mandruca and at Benghazi, on the Tripoli coast. There is also a good sort got from the islands of Cyprus and Crete. The Grecian Archipelago yields a fair supply, but their quality is by no means so good as those of the first-mentioned districts. The Bahama and West Indian sponges (Key West being the head-quarters of the fishing and export trade), though useful for many purposes, are quite an inferior sort, and not much in request with the London wholesale dealers.

Paradoxical it may sound, but, nevertheless, London, it is said, is the cheapest, and at the same time the dearest market—or rather, strictly speaking, commands the maximum market rate—for certain qualities of sponges. This arises from our metropolis forming the focus of the trade; and with quantity there necessarily will be gluts, and, temporarily, depression of value. On the other hand, a higher price is freely paid here for the rare and better sorts than elsewhere can be obtained.

As housewives and families know to their inconvenience and disappointment, a sea-side village, all amongst fishers, is not the place to be well served with fish, every catch being hurried off to the great town by rail. Thus, with sponges, the finest kinds come direct to England, where most nations buy. One of the better qualities, however, in a cleaned condition, finds its way to France. A commoner sort of the Turkey sponge is sent on to Southern Germany and Austria, by way of Trieste. Russia receives only the very poorest, coarsest sorts; while America, with her own sponge-producing banks, purchases the superior kinds in the English market. These data would seem to afford an index that ablution in Britain is, after all, of more frequent occurrence than our sanitary boards may admit.

In the wholesale market at present, Bahama and Turkey sponges range from 8d. to 35s. the pound weight, according to quality, but the prices as retailed are ruled by a somewhat arbitrary standard. A good-sized piece of a common West Indian sort may be had for a penny, or a few pence, whilst another kind of the Turkey sponge, no larger than one can easily grasp and squeeze in the closed fist, will cost from 5s. to 7s. or more; the same a little larger, proportionably to its bulk, brings even a much higher sum. The why and the wherefore of

this inequality in value will be readily comprehended from what has already been said as to the differences in fineness, &c., of the fibre. But, moreover, the prices of sponges of all kinds have enormously increased within the last few years, and in the year 1877, from several causes, were higher than ever before.

Fig. 11.—Sponges in natural Positions, rooted to Rock.

Mediterranean, or, as better known, Turkey sponges, are assorted by the dealers somewhat as follows:—(1) "Cups." These, as the name implies, are ordinarily cup-shaped—viz., a hollow centre and narrow, stalked end. The fibre of these is of varying degrees of fineness, softness, and elasticity, according to which range their values and prices. Though often of small size, this sort is greatly prized, and all bring by far the highest prices. (2) "Toilets" of all sizes. These vary in shape, being often rounded or flattened, or slightly modified cups. Their fibre is a trifle coarser than the preceding. (3) "Honeycombs" or bath-sponges, so named on account of their large perforated but unequal orificed honeycomb appearance. They are uncommonly large and dome-shaped, their fibre is stout and resilient, and the many wide holes both readily take in and part with water; and hence they are well adapted for bathing purposes. (4) "Toilet baths" are a modification of the two preceding. (5) "Carriage sponges," and (6) "Brown Turkey," are two of coarser consistence, varying greatly in size, toughness, and irregularity; generally, the last-named kind is not only of a different colour, but is also rough and hard-fibred.

The West India or Bahama sponges are now thus classed:—(1) "Common or Boat Sponge," with

white or yellow tissue, also known as "Sheepwool." (2) "Velvet Sponge," a sort with brown tissue. (3) Fine "Hardhead," with a fine large, brown fibre. (4) Coarse "Hardhead." (5) "Grass Sponge." (6) "Glove Sponge," which kind has large, fine, soft tissue, but which is not strong. (7) "Reef Sponge," a sort with small, fine, soft fibre, and generally of good forms. The two last and the first are regarded as the best sorts, but as a rule these Bahama sponges are both harsher, more brittle, and decidedly of a gritty fibre, as compared with the Turkey sponges. The West India sponge "fishery," it may be remarked, has of late years risen into considerable importance, spite of the inferiority of the material, and the trade bids fair still further to improve in value, since sponge has been applied to many new purposes.

As regards the finer sorts of Turkey sponges, they are comparatively, though not entirely, free from sand or gritty particles; whereas with the inferior kinds it is too often the reverse. Indeed, certain of those of the Bahamas are remarkable for the quantity of powdered shell-fragments and bits of coral imbedded in them. It is even stated that among these the worse kinds will lose as much as 75 per cent. of their weight when deprived of their lime-material. Another curious circumstance worthy of notice is that when the north winds blow in the Mediterranean, the sun-dried sponges then suck up so much moisture as to increase their weight by almost one-tenth part. The wily Greek traders then try to effect their sales, but the wary purchasers prefer to wait, while only the inexperienced dealer then buys.

From these facts it is evident that the merchant distinguishes a scale of qualities, absolutely based on differences and distinctions of structure. In his own way he thus classifies and appends a name whereby others may recognise, to a certain extent, the peculiarities of the object intended. Now this is precisely what the naturalist does, in specifically and generically naming and arranging the various sorts of living plants and animals.

It is therefore a good example of how the same principle is applicable in trade as in science. It is, so to say, an initiatory lesson in nomenclature and classification, unfortunately two stumbling-blocks to the spread and study of natural history. Certainly, it cannot be dissembled that long-sounding Latin names repel, and complicated arrays of divisions intimidate, beginners. But then it must not be forgotten that naturalists deal with an enormous number of facts, and as multitudinous a series of named plants and animals; thus technicalities like the merchants' assortments creep in, and beget terms in science not to be dispensed with, however much we wished. It is of the greatest importance, notwithstanding, that the spread of knowledge be not hindered by what, after all, is but the framework.

Besides the sponges of commerce, there are a vast number of other types—only met with, however, in museums, or occasionally as ornaments. Of these, it is not intended here to say more than that some contain much lime, others flinty material, and those like our common sponge, a horny substance. These distinctive skeleton characters, therefore, yield as many divisional Orders—viz., CALCAREA, SILICEA, and KERATOSA; though naturalists are by no means unanimous in adopting this grouping of the lowly-organised but nevertheless interesting Class, SPONGIDA.

## A VISIT TO A QUARRY.

By B. B. Woodward, British Museum.

OUR knowledge concerning the various rocks which compose the crust of the earth, has been derived from a careful study of the different beds exposed in the many sections, both natural and artificial, that are more or less abundant in all countries. The cliffs that fringe the sea-shore, or overhang the banks of some rivers, and the inland cliffs or "escarpments" that form such prominent features in many of our landscapes, are examples of natural sections; whilst among the artificial we may enumerate quarries, railway-cuttings, deep well-borings, &c. All the beds shown in such a section as that figured in the Frontispiece are not found at one place. Some are sure to be absent; but all bear the same relative position to the others, no matter how few or how many are found.

In our own country a greater number of different beds, or sets of beds, occur than are, probably, to be met with in any other tract of similar extent, and a fair knowledge of their nature and fossil

contents may be derived from the various rocks exposed in the faces of cliffs on our coasts; but the closest inspection of these sections would not enable one to trace out the direction and extent of the beds inland, which can be correctly ascertained only by consulting numerous quarry and other artificial sections, aided by a careful study of the physical features of the country. Then, again, beds of the same age may, in different localities, consist of entirely different materials, such as limestone in one place, clay in another, and perhaps sandstone in a third. An observer going from one to the other would be most likely to set them down as altogether distinct deposits; whereas an examination of the intermediate rocks exposed artificially in quarries, and their fossil contents, would enable him to trace the connection which really exists between them, and to demonstrate the identity of their age.

Besides, however, conveying especial information of this description, each quarry has its own version to give of the chapter of geological history that it illustrates; just as each copy of an ancient work will have its different readings and renderings of certain passages, whilst they all agree in the main facts stated.

How the geologists manage to coax—or rather to hammer—sermons out of stones, is to some a profound mystery, whilst others treat the whole matter with the most supreme contempt, for to them a stone is merely a stone, and a quarry a pit in which men are at work cutting out and carting off the rocks for various purposes. Passing by these latter, we will ask our mystified friends to accompany us by that safest and most easy method of transit, a flight of imagination, to the nearest quarry, of which a detailed view is here given (Fig. 1), where we will endeavour to initiate them into the secret of "how to read the great stone book of nature." The same means that conveyed us to the quarry has also furnished us with the requisite apparatus for pursuing our investigations—namely, a hammer, with one end of the head flat and square, and the other produced into a pick; a cold chisel, a pocket lens, a compass, a bottle containing acid, and a bag in which to put any

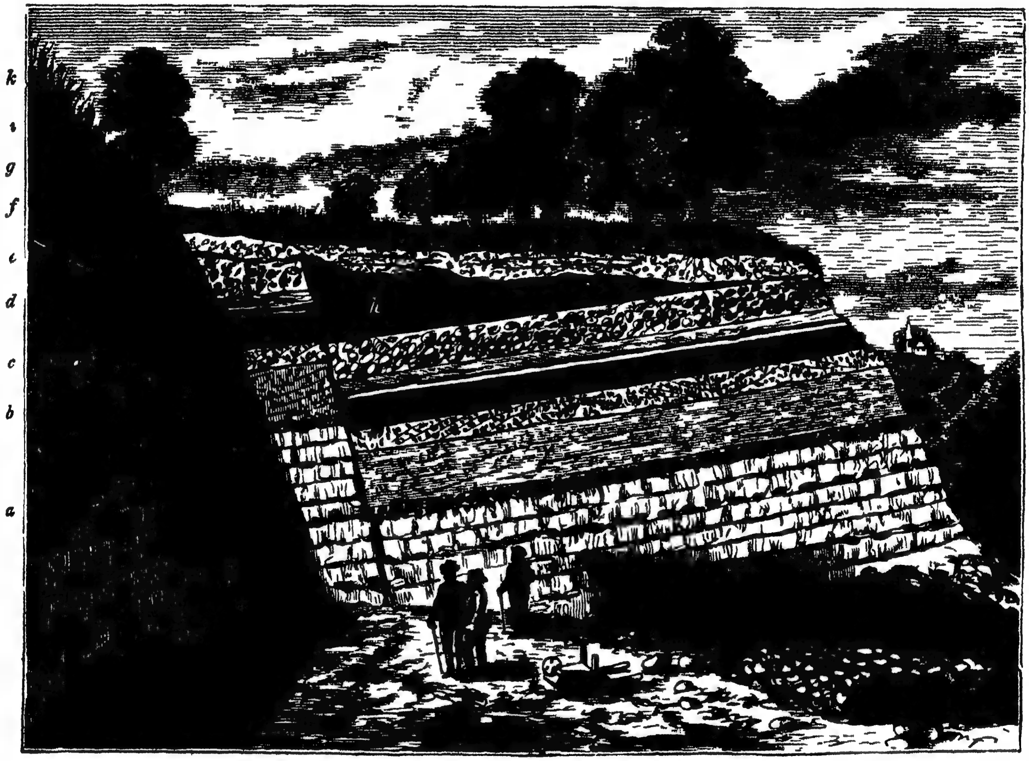



Fig. 1.—View of a Quarry "Section" or Cutting

specimens that we may wish to carry away with us.

As we stand thus equipped looking at the wall of the quarry which faces us, the first thing we notice is, that it is built up of a series of beds or "strata" resting one on the top of the other. Of these, the two uppermost are nearly horizontal, and for the present may be left out of the question. The rest are inclined at a considerable angle, and slope down to the left. Consulting the compass, we find that we are looking almost due west, consequently the beds slope down—or, to speak geologically, "dip"—to the south. The necessary result of this dip in the strata will be to cause the beds which are at the bottom here to come to the surface a little further north; and, on the other hand, to the south we should expect to find other and newer beds coming in and resting on the top of these. Originally, of course, they were all horizontal, that being the position in which they were deposited; but afterwards, owing to movements taking place in the crust of the earth, were tilted up as we now see them. Had it not been, therefore, for disturbances of this kind bringing the underlying rocks to the surface, none but the newest would be within our reach; whilst of the oldest—as, for instance, the Silurian and Cambrian (*vide* Frontispiece to this volume)—we should have known absolutely nothing whatever.

The next thing in the "section" that strikes the eye, is a large crack running down in a vertical direction through these inclined beds, which at first sight appear to terminate abruptly on reaching it, for they have evidently no connection whatever with those immediately opposed to them on the other side of the fissure. A second glance, however, shows us that the same series of deposits occurs on either side of it, but that the relative level of the beds differs, those on the northern side of the fissure being some feet lower than the corresponding ones on the southern side. It is perfectly clear that they must formerly have been continuous, and that subsequently they were fractured at this point, and the northern set let down some eight or ten feet, bringing with it a portion of a higher bed (*h*), of which we should otherwise have had no trace in this section.

Dislocations of this kind are termed "faults;" they are of common occurrence, and in some cases the vertical displacement of the beds can be measured by as many yards as inches in the present instance. They often give rise to striking physical features, as they afford lines of weakness along which the rains and frosts can act and cut out valleys for rivers to run in.

But we have been stopping long enough at the entrance. Let us now make our way down to the section and see what all these different beds are made of, and what is the history that each has to tell us.

The bottom bed (*a*) you will recognise at once. A pure white limestone, with layers of flint nodules at tolerably regular intervals, it can only be the well-known chalk. Microscopic examination has shown that the chalk is almost entirely composed of myriads of minute shells belonging to small beings, low down in the scale of life, known as *rhizopoda* or *foraminifera* (p. 14.) Now, these same little rhizopods swarm in the Atlantic Ocean at the present day, and their dead shells are forming at the bottom of that ocean a deposit precisely similar to the chalk, to which we are therefore perfectly justified in ascribing a like origin. The way in which the flints were formed is still a moot point; but the most probable explanation appears to be that the water of the chalk sea every now and again accumulated more flinty matter in solution than it could hold, and was therefore compelled to part with it, which it did by precipitating it to the bottom, where, when there was sufficient, it spread out in vast sheets; more generally, however, the flinty material collected in nodules around any decomposing organic matter that lay half-buried in the soft sediment, towards which it was attracted by certain chemical laws. And this is the reason that fossils are so often found imbedded in flint. Numerous fossils also occur scattered throughout the chalk—lamp-shells, sea-urchins, star-fishes, sharks' teeth, &c. One of the quarry-men is coming towards us with a hat full of these fossils; they pick out those they come across in the course of their work, and take the earliest opportunity of selling them. Here are two of the commoner kinds of the *echinoderms* or sea-urchins (Fig. 2), and here is a shark's tooth (Fig. 3). The fossil you hold in your hand is

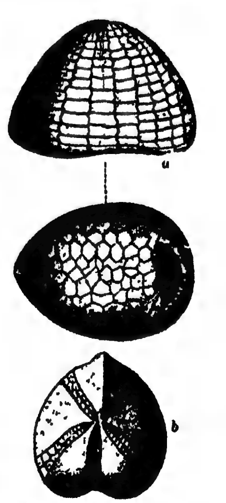



**Fig. 2.—Fossil Sea-Urchins.** (*a*) *Ananchytes ovatus*, side View and Base of the Shell; (*b*) *Micraster cor-anguinum*. (*After Lyell.*)

a "belemnite" (Fig. 4); it is part of the internal bone, or pen, of a species of cuttle-fish that lived in the chalk sea. The country people call them "thunder-picks," or "thunderbolts."

Fig. 3. — Tooth of an extinct Shark.

Having picked out what we want of these, together with some specimens of the lamp-shells (Fig. 5), we will wrap them carefully in paper to prevent their rubbing together, put them in the bag, and then continue our exploration of the section.

The upper surface of the chalk, we find, is not perfectly even, but is worn into slight hollows; and resting on this slightly uneven surface is a bed of flints (*b*), about one foot thick. You can see that they have been washed out of the chalk; still, they do not seem to have been much rubbed, and therefore cannot have been carried far; but they nevertheless represent several feet of chalk entirely removed, so that a kind of gap exists between the chalk and the overlying deposits. It is not so great a break as one we shall come to presently, but still, there it is, indicating that some disturbance or other took place in the physical conditions at this point, the results of which will be shown in the changed nature of the overlying beds. Trifling as it appears to the eye, this break is one of great importance; for if you will consult the table of strata in the Frontispiece, you will find that with the chalk the "secondary" rocks end; so that at this point we pass from one great division of the earth's strata to another, and at the same time from one great group of fossils to another, in which the forms of life are much nearer to those of the present day.


Fig. 4. — (*a*) Belemnite from the Chalk; (*b*) Belemnite restored. (*After D'Orbigny.*)

Resting on this bed of flints is a deposit of fine light-coloured sand (*c*). It affords no trace of a fossil, and if any shells ever were buried in it, they probably disappeared long ago, as beds of this sort allow the rain-water to percolate through them. Now, as rain-water generally contains acid, it dissolves the shells, so that unless the sand is pretty firm, not even a cast of them is left. Yet. from the appearance of the sand itself, we can tell that it is a marine deposit formed at no great distance from land.

The next bed (*d*) we find to consist of rounded black flint-pebbles, packed closely together, the

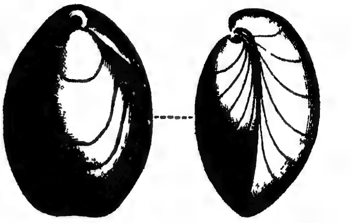


Fig. 5.—Fossil Lamp-Shells (*Terebratula*). (*After Lyell.*)

interstices being filled with sand. These pebbles have a rough bedding or "stratification" of their own, which runs at all angles to the direction of the bed itself, crossing it sometimes in one direction and sometimes in another, and giving rise to the appearance known as "false-bedding." Now, in a sea-beach the stones are of all sizes and shapes. Some are freshly broken, others are slightly rolled, the sharp edges being just worn off, and so on down to those that are quite smooth and perfectly rounded.

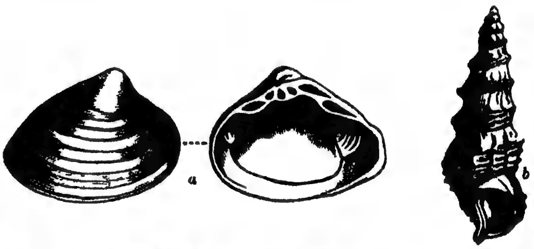



Fig 6.—Estuarine Shells from the Lower Miocene. (*a*) *Cyrena cuneiformis*; (*b*) *Melania inquinata.*

But in this deposit all have been reduced to the kidney-bean shape, so that this is not a mere beach deposit, but must have formed a shingle-bank a little way out to sea, in reaching which all the pebbles would get thus rounded and ground down. The appearance of "false-bedding" is due to the action of the waves and currents that piled them up. See, here is a shark's tooth amongst them, so those voracious creatures could not have been far off at the time! You will, however, be hardly likely to find much else there, so we will proceed without further delay to the next bed.

This is a mass of black clay (*e*). On the outer surface it has, by exposure to the weather, become hard and dry, but remains quite moist and plastic beneath. From top to bottom it is full of shells, arranged in layers. As the clay is impervious to

the passage of water, they are capitally preserved, except on the outer surface of the bed, where they have been subjected to the destroying action of rains and frosts. Some good specimens are easily procurable, and by packing them in a box with some dry sand we can convey them home in safety.

The shells shown in Fig. 6 belong to the class of molluscs that love to dwell in the mud at the mouths of large rivers, where the water is brackish. The clay, too, is exactly such as would be formed from the fine sediment brought down by some large river to the sea, and there deposited on the bottom. Hence we infer that this bed of clay is nothing more than the dried and pressed-down mud of some ancient estuary, whose turbid waters flowed over this spot in bygone ages. Before passing on, however, we must pause a minute to notice a ridge that juts out about the middle of this deposit, and is continued along its entire length. A tap of the hammer soon reveals its nature. Packed as closely as possible, and dovetailing, so to speak, into each other so as to form a hard band, are countless shells of oysters, often with both valves united just as they grew on the spot. As they prefer salter water than the other shells, they point to a slight change in the physical conditions at this stage, whereby the sea was enabled to gain slightly over the river, driving the estuarine shells back, and allowing the oysters to settle here, till a return of the previous conditions re-established the former occupants in their old quarters.

A somewhat different state of affairs is denoted by the succeeding formation (*f*). It is also a clay—very sandy, with thin seams or "partings" of pure clay. Its general colour is light-brown, and no shells are visible in it. By breaking off masses, and splitting them along the seams, the surfaces thus opened display a number of darker brown marks, which, when examined with the pocket lens, prove to be vegetable matter.

Small stems and the seeds of water-plants are abundant, whilst careful search is rewarded by the discovery of the perfect leaves of trees, which, if not identical with, are closely allied to some existing forms. The sandy nature of the deposit, and the presence of these vegetable remains, lead us to suppose that it accumulated nearer to the shore than the last, in quiet and tolerably shallow waters, out of the main current of some river. This stream was probably the same which furnished the black mud for the underlying bed, and which by this time had, owing to the seaward advance of the land, to carry its finer sediments further down, and only left here the heavier particles of mud and sand, and the waterlogged twigs and leaves of trees. At one period, however, the waters must have receded, leaving a swamp or marsh, in which various kinds of plants grew in abundance; for near the bottom of this bed appears a dark seam of "lignite," as it is called. If you examine a piece of this lignite under the lens, you will find that, like coal, it is entirely made up of vegetable remains pressed close together. Now, when vegetable matter buried in the earth is kept moist, and the air excluded, it commences to decompose slowly, and gives off carbonic-acid gas, thereby parting with a portion of its oxygen. By this means, it becomes gradually converted into lignite, and when this process of decomposition continues, the lignite is changed by degrees into common coal. So that the lignite is merely coal in an early stage of its formation (p. 87).

Succeeding this sandy clay with plant-remains, is another pebble-bed (*g*), similar to the one we passed a little lower down, only the pebbles are much larger and more oval in shape, showing that this shingle-bank was nearer the shore than the other. Here, too, amongst the stones at the bottom, are some shells of the same type as those in the black clay. A fresh inroad of the sea must, therefore, have taken place, and a shingle-bank been formed off the mouth of the river.

Above this, again, is the formation (*h*) which, as we had occasion to observe, was preserved to us through the occurrence of the fault at this spot. It is a dark-brown clay, dry and crumbly on the outside, becoming darker in colour, and stiffer, as you dig into it. That whitish, translucent substance that you have just picked out of it is the mineral called "selenite." A navvy would tell you that it was water "congealed by the moon;" it really is the crystalline form of sulphate of lime, and the crystals occur in clusters, radiating from a centre, falling apart when you attempt to excavate them. These clusters are all that remain of the fossil shells, once imbedded in the clay, that have undergone chemical change, and passed into this new form. You can readily split it with a knife, in one direction, into slices as thin as paper; but try and cut it in a direction perpendicular to this "cleavage-plane," as it is termed, and you will not be able to force the blade through it.

Only the two topmost layers now remain to be considered. These, as we saw before, are not affected by the "fault," nor do they dip to the south like the underlying strata, but rest in an almost horizontal position on the upturned edges of the

latter, which in places are worn into great hollows. A considerable period of time must therefore have elapsed between the deposition of the underlying beds and these two upper ones: a period sufficient to allow of the former being tilted up and "faulted," and the surface of the ground levelled before the latter were thrown down on them, all of which movements were effected by slow degrees, and not by any violent convulsions of nature.

In order to get some idea of the length of time thus consumed, it will be necessary to ascertain in the first place the geological age of the underlying inclined beds, and then that of the two horizontal ones.

Now, the sands, gravels, and clays which we have just been examining overlie the chalk, and are therefore newer than it. The chalk, we learnt, was the uppermost bed of the "secondary" series, so that these sands, &c., must be of "tertiary" age. The fossils they contain inform us that they belong to the lower portion of the lowest division of the tertiary series; a conclusion which we might have expected, though it did not of necessity follow, from their position with regard to the chalk.

So much, then, for our first point. Now for the second—the age of the topmost beds. To solve this, we must ascertain what they are, and inquire somewhat into their history.

The lower of the two (*i*) is clearly a gravel, and the upper (*k*) a clay full of big stones. The gravel is very different from the pebble-beds we saw just now. Instead of rounded flint-pebbles, it consists mainly of angular stones, and, while most of them are flints, there are also a great number of other stones derived from rocks of altogether a different sort to those found round about here. Furthermore, they exhibit no sign of being spread out by water action; there is no trace of any stratification whatever; they lie all jumbled together "anyhow," with here and there a mass of sand let in bodily.

A similar want of arrangement characterises the clay; there are no layers in it; it is one uniform mass from top to bottom; the big stones are scattered promiscuously throughout it in all sorts of positions; and it is so full of pieces of chalk, from the size of a hen's egg down to the smallest imaginable grains, that it has a whitish tinge. Break open some of these big stones or "boulders," and you will find that they are fragments of many different rocks. There are granites, basalts, and limestones of all ages. You can tell the limestones in a minute, for they can be scratched with a knife, and a drop of acid put on them begins immediately to "fizz." Many of these boulders are flattened and smoothed on one side, and covered over with long parallel scratches.

What, then, can have produced all these several results? And how were all these various stones brought together? There is only one agent known that could have performed all this work; that agent is—ice.

The sand and gravel was floated hither from some sea-beach, frozen in blocks of coast-ice, which stranding and melting deposited them at this spot; the boulders, detached by frosts and snows from their parent rocks, were smoothed and scratched by being fixed in masses of ice and ground against other rocks: ultimately they were floated down here on icebergs, and dropped into the glacial mud, which itself was formed by the wearing action of divers forms of ice upon the land (p. 38).

To geologists these beds are known as "drift," and, with the exception of the valley-gravels and alluvium, they are the most recent of the sedimentary rocks, as you will see by referring once more to the table of strata shown in the Frontispiece.

We have thus solved our second problem, and are now in a position to gain some notion of the immense break in time between these glacial drifts and the strata they rest on in this quarry. It cannot be estimated in years, or even hundreds of years, for it is impossible to form any accurate conception of the rate at which any given deposit accumulates; but we may be able to form some faint idea of its vastness when we realise the fact that this gap is elsewhere filled by beds some hundreds of feet in thickness, belonging to the Miocene and Pliocene epochs; that the great mountain-ranges of Europe attained their present elevations, by receiving an additional upheaval of several hundred feet; and, finally, that all the main physical features of the country were marked out in this interval, during the greater part of which this spot was, perhaps, dry land.

Here the record of the rocks in this quarry terminates. The neighbouring river takes it up and carries it on down to the present date; it could tell of the rude savages who dwelt on its banks in prehistoric times, and fashioned weapons of flint and stone, with which they fought or hunted the huge wild animals that roamed about. With these, however, we have on the present occasion nothing to do, and so turn homewards, laden, it is to be hoped, with some additional weight of knowledge, as well as the more tangible burden of fossils for the cabinet; reflecting by the way on the things

we have learnt from this visit to a quarry:—How that the past history of our earth, as related by geologists, so far from being a mere baseless myth, is a true account, founded on sound reasoning, and only to be learned by a diligent study of the phenomena in constant operation around us, and a careful application of the knowledge thus derived to the facts furnished by the various deposits—a process not more mysterious than the train of arithmetical reasoning by which we ascertain that two and two make four. We learn that the ground beneath us must have been formed at the bottom of sea, lake, and river, the particles of which it is composed being the results of the wearing away of some still older land-surface by the agencies of rain, frost, wind, &c., and the transporting powers of running water and floating ice. And now, when we next chance to light on a quarry of any description, instead of simply speculating as to the origin of the rocks we see in it, we may be able to set practically to work to obtain the information we desire concerning them.

## AIR AND GAS.

By J. E. H. Gordon, B.A., M.S.T.E.

WHAT does common observation teach us of the properties of air? Very little indeed. In our study of the machinery of the air we have not many common phenomena to guide us, as we have in the case of ice, water, and steam (*see* p. 28). Every one knows that ice melts when heated, and that hot water gives off steam; but in our present inquiry we have very little to start with.

We all know that when air is in rapid motion it exercises pressure.

Any one who has ever "popped" a paper bag knows that air, although it can be compressed, resists compression, and, in fact, presses out against the compressing force. We all know that air expands when heated—at least, every one who has noticed that hot air ascends will see by a little thinking that this means that a given weight of air occupies a greater space when hot than when cold.

In this paper we are going to explain some of these properties of air, and some other properties analogous to them, which will help to make their causes clear; to describe the effect of changes of pressure and temperature upon air and gases; and finally, to state the mechanical theory which we have strong grounds for believing to be competent to explain all the preceding phenomena.

For the present we will confine ourselves to atmospheric air, as it is the gas which is most convenient to experiment on, and, as we shall see, the properties which it possesses are common to all gases.

That air has weight may be shown by a very simple experiment (Fig. 1). From a large flask closed by a tap the air is pumped out. The tap being closed, the flask is placed in one pan of a delicate chemical balance, and counterpoised exactly by weights in the other pan. If the tap now be turned, and the air admitted to the flask, it will be found that the pan containing the flask sinks, and that more weights have to be added in the other pan to counterpoise it. These added weights are equal to the weight of the air which had been previously pumped out of the flask.

Fig. 1.—Experiment to show the Weight of Air.

The weight of 100 cubic inches of dry air at a temperature of 62° Fahr., and when the barometer stands at 30 inches, is about 31 grains. The same volume of hydrogen gas under similar circumstances would weigh 2·14 grains.

It may be added that water is 771 times heavier than air at the ordinary pressure of 30 inches, while both are at 32° Fahr.

We know that air can be compressed, and that it resists compression. An air-cushion is compressed a little when a light man sits on it, and a great deal when a heavy man does the same. We also know that the pressure of air increases as it is heated. If we blow a bladder full of air, and, having tied up the neck, place it in front of the fire, the pressure inside will increase, the bladder will swell, and when it can stretch no further it will burst.

Before we go on to examine the laws illustrated by the above phenomena, we must try and realise what is the essential difference between a liquid and a gas.

If we put a small quantity of liquid into a large bottle, the liquid will not fill the bottle; it will fill the lower part of the bottle, and there will be a level line at the top of the water. If, on the contrary, we take the largest possible bottle, and introduce into it the smallest possible quantity of air, or other gas, that gas will entirely fill the bottle; there will be no line of separation, and we shall not be able to say that there is more gas in one portion of the bottle than there is in another.

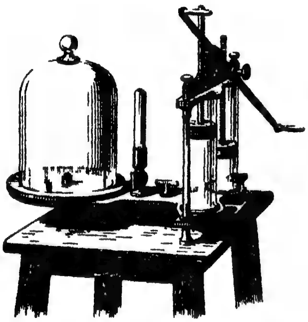


Fig 2. -Air-Pump.

A gas may, then, be defined to be, Matter in that state in which the smallest portion of it will entirely fill the very largest possible containing-vessel. In other words, gases have a tendency to indefinite expansion, which is limited only by the sizes of the vessels in which they are contained.

If we have an air-pump (Fig. 2), with several "pressure-gauges" attached to different parts of it, and if, after pumping out the air, we re-admit a small portion through any opening, all the gauges will rise equally; showing that the air has distributed itself uniformly in every part of the receiver.

We have said that if we increase the pressure of air, we diminish the volume. The question arises at once, How much diminution of volume will be produced by a given increase of pressure?

The question has been answered experimentally by Boyle and Marriotte, who worked independently and obtained the same result.

A tube of the form shown in the figure (Fig. 3) has a funnel at the top end, and has the short end closed by a tap. The tap being opened, a little mercury is placed in the tube so as to fill the bend. The air in the short arm is now at the same pressure as the external atmosphere. The tap is now closed, and more mercury is poured into the long end.

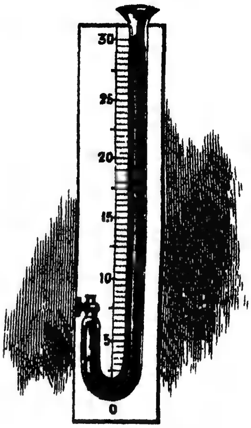




Fig 3 —Barometer

The mercury rises a little in the short end, but is prevented from rising much by the resistance of the air imprisoned; the height to which it rises shows how much the air is compressed. For instance, if from the first level of the mercury to the top of the short tube were six inches, and the mercury rose three inches, it would be shown that the air had been compressed to one-half its former volume

The height of the long column of mercury, or rather the difference of level between the mercury in the long and short tubes, shows the pressure to which the gas is being subjected. By observing the compression at a number of different pressures, the experimenters were enabled to enunciate the following law :—

"When the temperature remains the same, the volume of a given quantity of gas decreases in the same proportion as the pressure increases."

This means that, if we double the pressure, we halve the volume; if we treble it, the volume is one-third; if we quadruple it, one-fourth, and so on.

The same law holds for the expansion of air when the pressure is less than that of the atmosphere; but it is unnecessary to occupy our space by giving the modification of the above experiment by which the fact is established.

A necessary "corollary" of the above is, that if, instead of diminishing the volume, we double the quantity of air in a given vessel, we double the pressure.

Professor Rankine * has stated this law in another form, which places it in a very clear light He says :—"Let us take a closed and exhausted vessel, and introduce into it one grain of air. This, we know, will exert a certain pressure on every portion of the sides of the vessel. If now we

* Quoted by Clerk Maxwell ("Theory of Heat," p. 27).

introduce a second grain of air, this second grain will exert on the sides of the vessel exactly the same pressure as it would have done if the first grain had not been there before it. So the pressure will now be doubled, because the two grains together exercise double the pressure that either would have exercised separately."

Thus each portion of gas in a closed vessel exerts the same pressure against the sides of the vessel as if the other portions had not been there.

The total pressure is the sum of the pressures exercised by all the different portions, or, in other words, is proportional to the quantity of gas in the vessel; that is, that if, for instance, we have 3 oz. of gas exercising when alone a pressure, we will say, of 30 lb. to the square inch, and we add 2 oz. —which, if alone in the same vessel, would have exercised a pressure of 20 lb. to the square inch— the total pressure due to them both together is 50 lb. to the square inch; that is, it is the *sum* of the pressures due to each portion.

The quantity of gas in a vessel of unit volume is called the "density" of the gas.

This may also be expressed by saying that the density of the gas in any vessel is equal to the quantity of gas divided by the volume which the vessel will contain.

We may now say the density of a gas varies directly as the pressure, and the pressure exerted by any given gas varies directly as its density.

A little consideration shows that the proposition about the increase of pressure exerted by the gas when the volume is reduced is a necessary consequence of that about the diminution of volume when the pressure is increased, for when equilibrium is established, the outward pressure of the gas must be equal to the inward pressure exercised by the external forces upon it.

The same law holds for mixtures of different gases as holds for simple gases, for if a grain of one gas be put into a closed exhausted vessel, and then a grain of another, each will independently exercise its own pressure, in the same way as if they were two portions of the same gas.

What is called "Charles's law" is this:—Gases expand when heated. Charles discovered that at any pressure whatever, so long as the pressure is constant, the expansion produced by a given increase of temperature is constant, and the same for all gases. If at any pressure the volume of any gas whatever at 32° is unity, then, if the pressure remains constant, the volume at 212° will be 1·3665.

That is, 30 cubic inches of air at 32° will expand to about 41 cubic inches at 212°; and this law—namely, that the expansion caused by a given rise of temperature is constant—has been found to be true, not only for the range of temperature between 32° and 212°, but for every other temperature at which it has been hitherto tested.

Another way of stating this law is that, when not allowed to expand, the pressure of a gas increases by an equal amount with each degree by which its temperature is raised.

We have hitherto only stated a number of empirical laws about gases. We now proceed to the theory, which shows that all these, and many other phenomena, are necessary results of one simple natural fact, and further we shall be able to deduce from the theory facts about the internal constitution of gases which must for ever remain insensible to direct experiment. For if it, as in this case, is found that a theory explains every phenomenon out of a vast number observed, and contradicts none, we are justified in considering things to be proved which are necessary consequences of the theory, even when, as has been already stated, they can never be put to the test of direct experiment.

Prefacing, then, that the separate very small portions of which gases and other forms of matter are composed, are called *molecules*, we may briefly state the "kinetic theory" of gases as follows:—The molecules of all gases are in a state of rapid motion. They constantly strike each other and the sides of the vessel. The blows on the sides of the vessel form a continuous bombardment, and the bombardment *is* the pressure which the gas exercises on the sides of the vessel.

Now, as an illustration of the fact that a bombardment may produce a continuous pressure, let us take one of the machines seen at fairs for determining how hard one can hit. It consists of a cushion pressed forward by a spring. The blow compresses the spring for an instant, by an amount depending on the hardness of the blow. In the case of a single blow the compression is only instantaneous.

If, however, we had an *immense* number of men all hitting at once at a very big machine, but *not* keeping time, the spring would be permanently compressed—*i.e.*, the effect of the shower of blows would be to produce a steady pressure on the cushion. The amount of this pressure would be equal to the *average* strength of each blow multiplied by the *average* number which fell at once. When we are dealing with immense numbers, the law of averages approaches more and more nearly

to absolute exactitude. The error which we make in saying that the pressure of a gas whose temperature and volume do not alter is absolutely constant, is far smaller than the finest instruments ever likely to be invented could detect.

The actual pressure of a gas at any instant is seldom mathematically equal to the mean pressure, but the oscillations on each side of the mean pressure are of so exceedingly small an amount, and last each such an exceedingly small fraction of a second, that no experimental method can ever be expected to show the least difference.

The molecules, in their path from one side of the vessel to the other, are constantly striking other molecules, and by rebounding have the directions of their motions changed. Now, it is by no means necessary that any molecule should strike another in its path across the vessel, for the average free space between two molecules is several times the average thickness of a molecule. We can only say that, owing to the enormous number of molecules, and their great velocity, such a thing as a molecule getting across a vessel without striking another is very unlikely. It is much more unlikely that a large number—say half the molecules—should cross the vessel in the same direction without striking any other molecules.

It is, however, perfectly possible physically. Let us consider for a moment what would be the effect of half the molecules of air in a glass bottle simultaneously travelling to one side of the bottle, and the other half to the other, without any collision on the way. The total blows struck on the sides would be so powerful that the bottle would be instantly blown to atoms.

I need not say that such an event as a bottle of cold air exploding has never occurred, but the reason why it has not is only that the chances against the necessary arrangement of the molecules taking place are so great that they are practically infinite. There is no physical reason against such an occurrence.

This theory at once explains Boyle and Marriotte's law; for the pressure of a gas is proportional to the strength of the average blow of each molecule multiplied by the number of blows falling in a second. If we double the number of molecules by doubling the quantity of gas, we do not affect the hardness of the blows, but we double the number per second, and hence double the above product—that is, we double the pressure.

Now, this is the law which Boyle and Marriotte discovered experimentally. Again, the law of Charles. It can be shown by the theory that the temperature of a gas depends in a particular way on the average velocities with which the molecules are moving. Also the theory shows that the average blow depends, in the *same way*, on the velocities with which the molecules are moving.*

Hence, the theory shows that the average blow varies directly with the temperature.

Now, if without altering the number of molecules—that is, without altering the quantity of gas in the vessel—we increase its temperature, we shall, according to the theory, cause an increase of pressure proportional to the increase of temperature, for the pressure is:—The average blow multiplied by the number of blows. Doubling the average blow then doubles the pressure.

But this is one form of the law of Charles previously discovered experimentally.

The theory has stood the test of experiment in many other cases which are too complicated to be explained here, and it may be considered to be completely established.

Mathematicians have therefore been justified in going on to deduce from the theory propositions about the motion of the molecules which cannot be tested directly by experiment.

The only one which we shall give here is the deduction of the mean velocity with which the particles of hydrogen gas at rest under the ordinary atmospheric pressure, and at a temperature of 32° Fahr., are moving.

It is found that the average velocity is about 6,097 feet, or nearly $1\frac{1}{4}$ miles, per second.†

Thus we see an example of a strictly scientific process. A theory has been tested by its accordance with known facts, and has been applied to measure with absolute accuracy the velocities of molecules so small that millions of millions are contained in a cubic inch, and which are moving some 60 or 70 times as fast as the swiftest railway-train that ever ran.

* Both depend on the square of the velocity. See Maxwell, on "Theory of Heat," ch. xxii.

† This quantity, which is nearly the average velocity, is the exact square root of the mean of the squares of the velocities.

# SOME ANIMAL HISTORIES.

By Andrew Wilson, Ph.D., F.R.S.E., etc.,

*Lecturer on Zoology in the Edinburgh School of Medicine, and Examiner in Natural History and Botany in the University of Glasgow.*

THERE are few readers who have not regarded with interest the development of a butterfly, or who have not some idea of the curious series of changes through which that insect and most of its neighbours pass during their development, and before they attain the adult state. The school-boy who keeps "silkworms" can tell us that after a period of tolerable activity these somewhat phlegmatic pets will fall into a state of stupor, from which they wake up only to spin a silken thread, and (Fig. 1) to invest themselves in a literal tomb. But the silkworm's history, as every one knows, ends not thus. After a period passed within its cocoon, to all outward appearance in dull, passive inactivity, the creature wakens up to newness of life. The cocoon bursts open, and there issues therefrom a creature utterly different from the one which entered the silken abode. Then, we beheld a worm-like animal, whose whole existence was occupied in an intense devotion to its commissariat, and whose neighbours, in their too exclusive attention to the leaves in our gardens, caused wrath and dismay to prevail within the gardener's mind. Now, we see the silk-moth, a winged creature, full of activity, which bursts its cerements and takes instant flight as if eager to test its new-born powers. If we watch the development of a butterfly we shall be still more forcibly impressed with the differences which are seen to exist between the early and the mature condition. The caterpillar, grub, or *larva*, of the butterfly, like the silk-moth's ancestor, is developed from one of the numerous eggs which its parent deposited as it flitted over the plants of the garden. Like the grub of its near relation — the silk-moth—this butterfly-larva spends its existence in nourishing its worm-like frame. Whilst the perfect insect possesses a mouth adapted for drawing from the inmost recesses of flowers the rich stores of sweets which are therein formed, treasured, and concealed, its caterpillar-young is provided with a mouth suitable for tearing and triturating the leaves and other plant-tissues on which it feeds. The internal structure of the larva also diverges widely from that of the perfect insect; and it is, as we have seen, wingless; being forced to crawl over the surfaces of leaves by the contractions of its body, aided by six front legs and by certain short stumps placed at the rear of its body and provided with suckers. Sooner or later, this voracious grub will cease its epicurean existence, and make unto itself a cocoon of some kind. Within this temporary dwelling-place, outwardly so stable and quiescent, changes of curious extent and of sweeping nature are proceeding. There ensues, in fact, in the history of the caterpillar, a stage of complete dissolution. In one aspect, indeed, it might be thought that a literal reign of anarchy was being inaugurated

Fig. 1.—Metamorphosis of the Silk-Moth (*Bombyx Mori*), showing Larva, Chrysalis, and Moth.

within the animal's body. Its organs and parts are being broken down and disintegrated, and no one portion of its frame appears exempt from the work of wholesale destruction, which thus would seem in a short space of time to bring to naught all the work and labour of its previous life.

curious and as yet ill-understood process, the vital forces, operating within the cocoon, are building up a new body from the materials afforded by the old. The voracity of the caterpillar has not been without a good purpose, in that the animal has accumulated a store of material out of which

Fig 2.—Transformations of a Butterfly.

In the study of nature, however, as in the concerns of ordinary life, it is a wise procedure to look for and to understand "the other side" of the questions submitted for our approval. That another than a destructive aspect may be readily traced in the history of our insect's development, is clear enough, if we simply look forward to the final result of its life-history. The work of reconstruction and repair succeeds, and, in large measure, may be said to keep pace with, the destructive phases which proceed within the body of the caterpillar. By a

its new habiliments will be formed. As the work of reconstruction proceeds apace and is duly completed, organs and parts unknown in the caterpillar will be found to have been developed as essentials of the perfect insect's frame. And with the completion of this wondrous operation—performed none the less perfectly because it is so silently conducted—the butterfly, like a veritable phœnix, renews its youth, and issues forth on its new existence, to live henceforward, mid the sunshine and flowers, as the type, in the eyes of poetic humanity

at least, of all that is gay and careless, elegant and beautiful.

Thus, the life-history of a butterfly, or moth, shews us three well-marked stages the *larva* or caterpillar, the *pupa* or *chrysalis*, and the *imago* or perfect and winged insect. We have also noted that the animal issues from the egg as a veritable worm; that it spends its larval condition in the work of nutrition; that its structure in this condition is essentially different from that of the perfect insect; and that within its chrysalis-case the elements of the larval body are dissolved and disintegrated, and are thereafter built up anew to form that of the winged and mature form.

Fig 3.—Larva of Dragon-fly (*Libellula*). (The right-hand Figure shows the Pupa emerging from the larval Skin).

The butterflies, beetles, flies, and their neighbours, present us with examples of insects which undergo the most complete series of changes known in their class. To the series of changes which insects undergo in the course of their development, the name of *metamorphosis* has been given; and, as we shall presently observe, there are certain other groups of animals which divide, with the insects, the interest we naturally take in the discovery and investigation of curious life-histories.

But within the limits of the insect-class itself, there are very marked variations to be noted in the degree of perfection which the metamorphosis may exhibit. The Butterfly's development may for all purposes be regarded as presenting us with the most typical example of this process; and when we compare the life-history of such an insect as a Dragon-fly or May-fly with that of the Butterfly, we may readily discern differences of a very marked kind to exist between the two cases. From the egg of the dragon-fly comes forth an active, long-bodied creature (Fig. 3), that presents a close enough resemblance to a caterpillar to enable us to regard it as the larval form of the "tyrant of the pool." As in the case of the butterfly's progeny, there is in this first stage no likeness to the perfect dragon-fly. The very long, powerful wings, and the slender, tapering body (Fig. 4), are not represented in the dragon-fly's young, whilst in its habits the larva is likewise far removed from the similitude of its parent. It possesses, however, six legs attached to the chest-region; its large head bears two compound eyes of great size; and the furnishings of its mouth are still more characteristic. For this juvenile insect possesses a very long lower lip, which is not only highly movable, but bears at its extremity two enlarged hooks, or jaws. Armed with this apparatus, which can be folded up on the face after the fashion of a "mask," the young dragon-fly crawls, an apparently innocent-looking being, over the floor of its native pool—for it is strictly a water-living animal in its early life. When, however, any unwary co-tenant of the waters approaches the larva, the "mask" is literally as well as figuratively thrown off (Fig. 3), and the jaws seize the victim and securely retain it. Besides its power of crawling over the bottom of its pool, the young dragon-fly may leap or propel itself forwards in the water by a curious contrivance, which reminds one of the mode in which the cuttle-fishes move. From the hinder extremity of its body, and from a kind of chamber

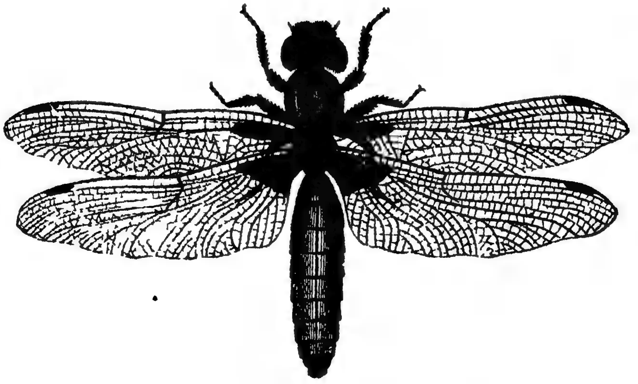


Fig. 4.—Mature or "Imago" Dragon-fly

within which the breathing-organs—half gills, half air-tubes—are contained, the water, from which the necessary air has been taken, can be forcibly ejected; and through the reaction of this *jet d'eau* on the surrounding water, the young insect is propelled rapidly forwards.

The young dragon-fly, whose structure has been thus briefly detailed, moults several times, and, when it has become a creature of larger growth, appears before us as the pupa or chrysalis. Unlike that of the butterfly, the young of the dragon-fly does not inclose its body in a cocoon or pupa-case. On the contrary, it is as free and as active in its chrysalis state as in its larval condition. The chrysalis differs from the larval dragon-fly only in its larger size, and in the better development of the organs which represent the future wings. The end of this chequered career, however, looms in the distance. A day arrives, when, after a period marked by increased activity and restlessness, the chrysalis attaches its horny body to the stem of some water-weed. Here destruction and annihilation seem at first sight to await the being; for soon its back splits open, and disorganisation seems to threaten its existence. This act, however, is but the prelude to the perfection of its life. For, from the rent frame of the chrysalis, and from the confines of the lower body, there issues forth the perfect dragon-fly. A short interval elapses. The insect, at first feeble and unaccustomed to its new state of existence, rests awhile on the friendly stem that still bears its cast-off swaddling-clothes. And when its wings have dried and stiffened, and its vital functions have had time to settle down to work, the insect rises into the air in the full enjoyment of its new-born powers. Very aptly, and in the happiest of moods, has the Laureate described the scene in which the eye of poet and naturalist alike may delight—

> "To-day I saw the dragon-fly
> Come from the wells, where he did lie.
>
> "An inner impulse rent the veil
> Of his old husk; from head to tail
> Came out clear plates of sapphire mail.
>
> "He dried his wings, like gauze they grew;
> Thro' crofts and pastures wet with dew,
> A living flash of light he flew."

In our survey of life-histories, we may now pass from the insect-group, to a nearly-allied series of animals—that of the *Crustacea*—represented by the barnacles, water-fleas, crabs, lobsters, and by many other less familiar forms. Within the confines of crustacean life, we shall find metamorphosis to be represented in very typical and plain detail. Let us visit the sea-beach, and in imagination try to recount the history of some of the creatures which surround our weed-girt path! There, for example, is that angular animal the common shore-crab, type of all that is awry and cross-grained in humanity. Awkwardly he sidles along, glaring defiance at us through his great eyes—which literally rise out of his head on short stalks—as he proceeds to bury himself in the sand, doubtless fancying—if crabs ever fancy—like the ostrich, that, if he does not see his foes, his foes will miss seeing him. Our crab is by no means an elegant animal. That he is a beautiful or comely creature, his most enthusiastic admirers amongst zoologists will hardly assert. But we may discern the cause of the interest with which the naturalist regards the crab, if we seek to trace his biography, or suppose that he relates it in his own words:—

"When I left the egg in which I first made my appearance—and which my mother carried about beneath her "purse" or tail, as you doubtless have noticed, in company with some hundreds of my

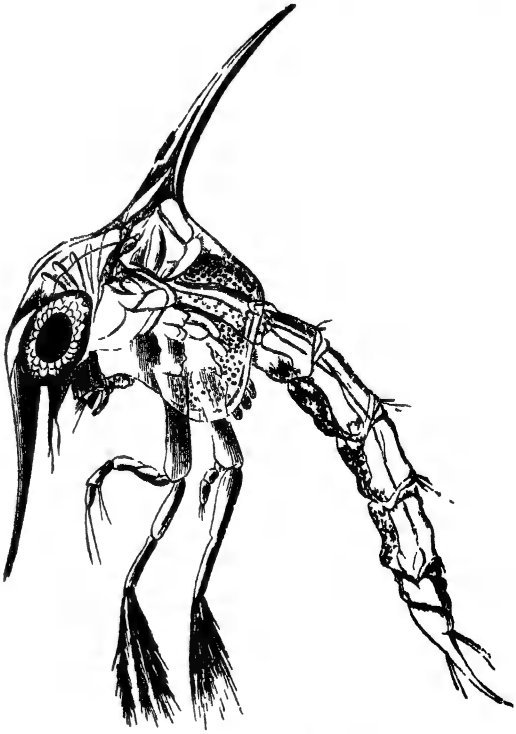


Fig 5.—Larva or *Zoea* of Crab.

brethren and sisters—I appeared as a little free-swimming animal, possessing a body looking simply like a very big head. In this stage naturalists

called me a *Zoea* (Fig. 5); and when I was first discovered, I was thought to be a new species of crustacean, since my relationship to my awkward-looking parent or to my present self was not in the least suspected. A long spine arose from the back of my head like the top of a nightcap long drawn out; and another spine or process projected below, like a veritable beak. Being an active little creature, I was provided with two very large organs of sight, which, had you seen them, would have reminded you of a pair of bull's-eyes in a lantern. I had a long, jointed tail by way of balance to my head or body; the last joint of this appendage being broadened out; and I possessed in all three pairs of leg-like organs. One pair, borne in the front of my head, represented one set of the feelers you see I now possess; and the other two pairs, with which I paddled my way along, corresponded to four of the jaw-feet with which I now chew my food.

"I was forced, through circumstances over which I had no control—for one cannot help growing, of course—to change my outer garment or skin more than once. At last a day arrived when I might fairly be said to have attained the fulness of my youth. My body had now grown to a respectable size, and to a shape not very different from my present conformation. My eyes became stalked as you now see them, and whilst my tail was now better developed, my limbs had also grown; and I became possessed of five pairs of limbs, the first pair being my 'nippers,' the strength of which you are welcome to test, if you like. In short, I became what zoologists call the *Megalopa*—that is, the boy-crab—just as the *Zoea* is my infantile stage. I did not alter much after the megalopa state. Of course, my tail gradually grew less, as my body increased; and now you may see my rudimentary tail, in the shape of my 'purse,' which is tucked up under my body, and which mischievous children are so fond of pulling down to see what I conceal under it. They find nothing but a few feet in an elementary condition; and of course you can see that, had my tail persisted in its early state, and had it continued to grow with my body, I should have resembled my friends the lobsters and shrimps. Only I am just as glad that I do not possess a tail, for I consider—and naturalists tell me so—that I am the lobster's superior: just, indeed, as I fancy you consider yourself the superior of Pongo the gorilla, and his neighbours, because the human tail has become rudimentary from unknown causes, or has become worn away—as one of your species, the learned Lord Monboddo, maintained—by your habits of sitting on it. Be that as it may, the crab who now addresses you was once like an erratic shrimp on a roving commission, and has become the staid being you know me to be through the degeneration of my tail, and through the greater growth and development of my head and chest. In fact, my body is all head and chest together. That is my history. I hear—for I possess ears—the tide flowing in; so I must burrow once again in the sand, as my gills require moisture. Fare you well."

A walk across the tangle-covered flat before us to yon rocks that run out into the sea and appear at low water like the outline of some huge creature resting in shore from its battles in the main beyond, will bring us into "fresh fields and pastures new" in the way of subjects for investigation. As you pass over the rocky ledge, you tread under foot by the hundred the little animals whose conical shells are the detestation of waders, and which are massed together on every available fragment of rock-surface, in utter defiance of all laws as to overcrowding. The creatures whose shells you see incrusting the rocks and stones everywhere at low-water mark are the *Balani* or "Sea-acorns." They are near relatives of the barnacles which you have seen clustered on a piece of wave-tossed timber (Fig. 6), or that you have observed incrusting the sides of ships which have been docked for repairs after long voyaging in tropical seas. The barnacle is, in fact, a sea-acorn *plus* a fleshy stalk. The bodies of both animals are of essentially similar structure; and, as regards their life-history and development, the one may be said to be the prototype of the other. Moreover, both animals belong to the Crustacean class, and may be regarded as far-off cousins of our crab. A comparison between the structure of the crab and the barnacle would show us that the latter is simply a crustacean attached head downwards within its shell, and which "kicks its food into its mouth with its legs," to use the figure employed by a very great authority in matters zoological and otherwise. The said legs exist, however, in the barnacles and sea-acorns in the form of a dozen filaments, each of which, being divided at its tip, gives to the animal the appearance of possessing twenty-four of these processes. Drop the first stone, or oyster-shell, you can find with living sea-acorns attached to it, into a vessel of sea-water, and you will be amply repaid for your small outlay of trouble by seeing how the animal uses its feet. A little trap-door will open at the mouth of the shell, and immediately there will be protruded the twenty-four filaments, which, like a set of beautiful

waving plumes, will be seen to keep up a constant circulation of water round about the animal. shell: snap goes the little trap-door at the top, and the animal is secured within its abode.

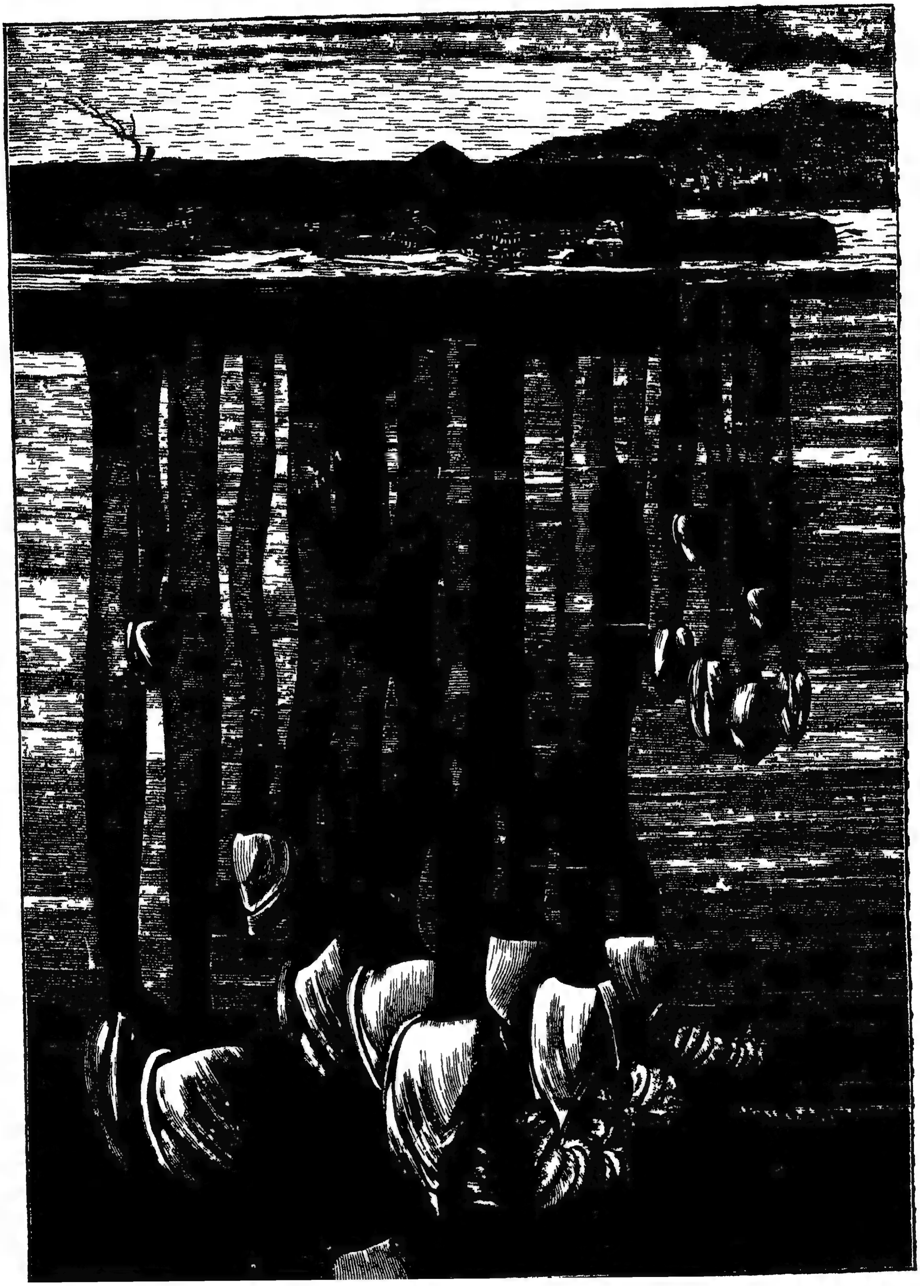


Fig 6 —Group of Barnacles attached to a floating Log

Thereby particles of food are "kicked into its mouth," and probably the function of breathing is also performed by this action On the slightest alarm the feet are at once withdrawn into the

We have, however, less to do with the fully-grown barnacle or sea-acorn than with their infantile stages. When we secure a ripe egg of either animal foı microscopic examination, we shall

find the little creature to be contained therein. but, like the young insect or crab, to present no likeness to the full-grown creature. Here is an embryo, or young form, which has just escaped from the egg, and is hurrying off seawards to "see life," without doubt, and to begin life in earnest as well. You now behold a little body, which, roughly described, we shall say has a triangular shape. It has a tail behind, and the shield or "shell" with which the little body is covered, is prolonged in front and at its side-angles or corners into spines or horns. Three pairs of feet, or appendages that resemble these organs, are possessed by the infant barnacle, the two hinder pairs being forked at their tips and provided with long bristles. A single eye appears in front of the two foremost "feet;" and a mouth, stomach, and intestine are discovered within this little body. Thus provided within and without, this little Cyclopean creature swims merrily through the sea. In this stage it is universally named the *Nauplius*.

Like the young crab, our nauplius moults frequently, and grows perceptibly after each change of skin. By-and-by it alters its form. It becomes a *pupa*, and in this stage possesses an oval body, whilst the single eye has been replaced by two of these organs. What were the two foremost feet in the nauplius are now seen in the pupa to be the *antennæ* or "feelers" of the animal, and these feelers are each provided with a sucker; whilst the furnishings of this curious little being are completed by the appearance of the rudiments of six pairs of appendages which are developed just behind the mouth. Now ensues what is, perhaps, the most curious part of the life-history of the barnacle or sea-acorn. Certain organs known as *cement glands* have been found within the body, and these organs manufacture a kind of strong marine glue, which is poured out at the tips or suckers of the feelers. The hereditary instincts of the young animal now lead it to seek a place of attachment. The roving life has to be given up, and the existence of the staid and fixed adult begins. A floating log of wood in the case of the barnacle, and a shell or rock in the case of the sea-acorn, present the desired objects for fixation. Attaching itself by its feelers, as a temporary measure, the young animal throws out its cement and renders its hold secure. Eyes, limbs, and other appendages, are thrown off; the characteristic shell of the animal is developed; and from the stage represented by the free-swimming nauplius the creature has merged into the rooted barnacle or sea-acorn.

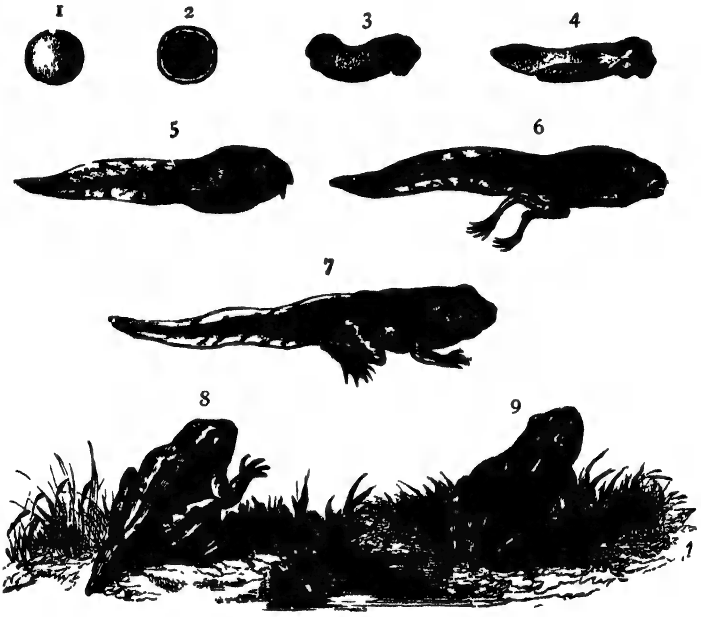
Two more examples may be selected by way of comparison with the preceding case, from the great Crustacean class. We know of a shrimp, *Peneus* by name, which in its youngest stage resembles the nauplius of the barnacle—a creature closely related to the crabs and lobsters, thus mimicking, as it were, its lower neighbours in its young condition. Then also, adherent, like unwelcome guests, on the soft bodies of hermit-crabs as hosts, we find queer little bags, each of which, in reality, is by no means unlike a German sausage, of curved shape. You might, at first sight, assume such a curious structure to be some abnormal outgrowth or tumour, requiring the kindly aid of some professed "surgeon to the Crustacea" for its removal. Each little bag or sausage-growth is named a *Sacculina;* and the interesting question, "What is a sacculina?" arises for consideration. If we adopt the common-sense plan, we shall try to find out the nature of the organism by investigating its structure, external and internal. Outwardly, sacculina seems to be a small, soft bag, with a lower orifice through which water is taken in and expelled by slow contractions of the bag itself. It is attached to the crab by a veritable series of roots, which penetrate within the body of the latter animal, and entwine themselves amidst the intestines or the substance of the liver. Open this sac-like body, and apply the highest exercise of anatomical skill towards unravelling the mystery of its identity, and what do you find it to be? A bag of eggs, and nothing more. No clue to its identity can therefore be founded on the dissecting-knife. It may be almost any kind of back-boneless animal, as far as our anatomical information is concerned; and had we no other source of inquiry, the relationship of sacculina would stand a very small chance of being resolved or determined.

But let us watch the development of one of the eggs contained in this sac-like parent. The puzzle that anatomy may not solve, the study of a life-history may render plain. From sacculina's egg escapes a little creature in which we recognise a striking likeness to a familiar friend. This little organism possesses an oval body, covered by a kind of shield, and three pairs of swimming-feet, provided with bristles. The resemblance of the young sacculina to the young barnacle is too close to be mistaken—albeit that the former wants a mouth and digestive apparatus. It is also known as a Nauplius, and, like the young barnacle, swims freely in the water. Soon the young nauplius of sacculina becomes a pupa. Its back-shield now becomes folded downwards, to protect its body, as the boards inclose a

book; and, as if to further increase the likeness to the young barnacle, the first pair of feet become feelers or organs which are ultimately destined to attach the sacculina to some fixed object. Filaments, supposed to be the germs of the "roots" by which the animal adheres to the body of the crab, are seen to grow out of the ends of these "feelers." The other two pairs of appendages with which it was originally provided are cast off, and six pairs of divided feet appear to be developed on the hinder portion of the body; the tail being at this stage also divided and forked. Seeking and finding a crab-host, the feelers become attached to the body of the higher crustacean and develop into the sacculina-roots. The feet are wholly cast off, as also are any other structures which the nauplius may possess; the result of this physiological backsliding and retrogression being the production of the inert bag-like sacculina with the observation of which our recital began.

By way of concluding examples of curious life-histories, we may only remark the fact that star-fishes and sea-urchins are developed from a secondary larva, which appears to be produced within the body of a first larva; whilst amongst the zoophytes, sea-squirts, and other animals, there are to be found many curious illustrations of metamorphosis, both of a common and of extraordinary type. Space will permit of reference only to one or two cases of metamorphosis amongst higher animals, and of the mention of a few inferences which may be drawn from our present subject by way of conclusion.

The higher animals just alluded to are included in the class *Amphibia*, or that to which the frogs, toads, and newts belong. That the frogs and their allies come from the egg in the form of the well-known "tadpoles" is a fact familiar to everybody. Within the egg (1, 2, 3, Fig. 7) the young frog is fish-like in form, and after escaping therefrom developes three pairs of gills (4) on the sides of the neck. These outside gills are replaced by internal ones (5), and thereafter the hind-limbs become first apparent (6), and are shortly followed by the fore-members (7). Meanwhile, lungs are being developed, and when those organs and the limbs have attained a certain stage of perfection, the internal gills disappear; the tail becomes rudimentary (8); the frog leaves the water (9); breathes for the rest of its life by lungs alone; and dwells henceforward on land, although entering the water readily enough if so disposed. The well-known newts or efts, which, in the vulgar mind, have long been regarded with aversion and dislike on account of the supposed possession of poisonous qualities, are near neighbours of our frog.



. 7.—METAMORPHOSIS OF THE FROG.

Although habitually living in the water, the newts are, nevertheless, as truly lung-breathers as are the whales; and, like the latter animals, have to ascend periodically to the surface of the water for the purpose of inhaling air. Like the frogs, the newts pass through a very definite and similar series of changes in development; the only difference we may note between the development of the two animals being that whilst the frog gets rid of its tadpole tail, the newt retains that appendage. Thus we see that our frog in its first stage of development, and whilst in the tadpole state, is essentially a little fish, in respect of its gills, heart, and other structures. Then it resembles one of its newt-like or tailed neighbours, which—like the Proteus, Siren, and other forms—possess both gills and lungs throughout life. Whilst, lastly, when the frog-characters succeed the fish like characters, the tail and gills disappear, and lungs, as we have seen, form the sole breathing-organs of the adult animal.

Some relatives of the frogs included in the Newt-order, exhibit certain very instructive points in connection with their development. For instance, the Axolotl of Mexico, a newt, possessing both outside gills and lungs in its adult condition, is known occasionally to shed its gills; to slip out of its axolotl-skin; and to metamorphose itself in a most inexplicable manner into the form of an entirely different creature—the *Amblystoma*, one of the Land Salamanders of North America. The surprise with which this discovery was greeted by naturalists may be imagined since the transformation in question was not a whit less strange than would be the changing of a frog into a toad, or of any one species of animal into an entirely different species. The axolotls have been artificially changed into amblystomas through the painstaking care of a lady experimenter, who showed that by enticing the animals out of the water, and by gradually inuring them to the dry land, they cast their gills and assumed the colour and lung-breathing habits of their pseudo-selves, the amblystomas. The present case therefore shows us that metamorphosis is not confined to the early life of animals, but may sometimes occur during their apparently full-grown and adult condition. Another relation of our frogs which is decidedly a strange being in respect of the influence of a change of *habitat* on its form, is the Black Salamander or Land Newt of the Alps. Like all its kindred, this animal begins life as a "gilled" tadpole, but with this difference or qualification—that from the absence of water wherein to disport itself in its young state, it has come to pass through its metamorphosis *within the body of its parent.* So that when it passes into the outer world its gills have been already shed, and it is found to be provided with lungs for the pursuit of its terrestrial existence. When a young Black Salamander is taken from the parent-body in its tadpole and "gilled" condition, and placed in the water, it lives therein, uses its gills as breathing-organs, and at a time when, had it been left to nature, it might have been a true land-living salamander like its parent, it may thus swim about a truly aquatic animal. But sooner or later it casts its gills, and emerges upon the land to breathe, during its after-life, by lungs alone.

It is but a poor story which has not a moral or application; and whatever be thought of the importance of this brief recital regarding metamorphosis, there can exist—in the minds of naturalists, at least—no doubt whatever regarding the important lessons concerning animal life which the examples we have given are calculated to teach. If we summarise these lessons or applications, by way of conclusion, the chief inferences will be readily appreciated by the reader.

*Firstly*, then, metamorphosis must be regarded as a curious phase of development, in which the young leave the egg at a comparatively early period of development, and undergo the remainder of their development as more or less free and active individuals.

*Secondly:* We account for the differences which are seen in the metamorphoses of various animals belonging to the same class (as in the case of the insects) by the explanation that the larvæ and pupæ have been variously affected by their surroundings; and have acquired (as we noted in the case of the axolotls and Land Salamanders) new habits, according to the circumstances in which they have been placed.

*Thirdly:* We see in the development of an animal a panoramic picture of the stages through which its ancestors may have passed, and through which these ancestors have tended to produce its present form. This, we need not tell the reader, is the view of Dr. Darwin and his followers. On the ideas just mooted, they would say that the frog was derived from a fish-like creature represented by the tadpole, and that it next became a newt-like or tailed animal, breathing by both gills and lungs; whilst ultimately it became a frog through the disappearance of the tail and gills together. The Land Salamanders would thus seem to have been evolved from gilled and water-inhabiting forms. Insects, on the same theory, may have originated from a

worm-like progenitor represented by the larva; and there is little need to point out the "Nauplius" as the representative of the far-back progenitor of the Crustaceans. Whether this is true or not, it is impossible to say. It must be confessed, however, that the supposition is not only highly probable, but that it is also not a whit more wonderful or strange than the fact of finding that creatures so widely different as are a sacculina, a barnacle, a shrimp, and a crab, begin life in one and the same form.

*Fourthly:* We may obtain in metamorphosis and development the only sure clue and test of the relationship of animals, by seeing the close likeness of animals which are true neighbours in the young state—a fact already illustrated by the case of Sacculina, whose relationship to other crustaceans is thus proved.

*Fifthly:* We see that there may be backsliding as well as progression in development, and that the process does not always tend to evolve a higher form from the young or early state. The young sacculina and the young barnacle are in reality animals of higher organisation than they appear in their adult stages.

*Sixthly*, and lastly: The subject before us proves conclusively how powerfully the surroundings of a living being affect its whole existence. The water-living axolotl when shifted from water to dry land becomes a land-animal; and when a young Alpine salamander can find no water wherein to pass its tadpole and gilled stage, nature compensates it for the loss by inducing the habit of undergoing its metamorphosis within the body of its parent. And we finally learn, that in reality there exists a much larger share of sympathy between living animals and the world in which they live than could by any one at first sight, or without some knowledge of their life-histories, have been supposed or conceived.

# A PIECE OF COAL.

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To what precocious intelligence and insight, to what happy instinct of untutored genius, we owe the first discovery of the properties of coal, we may never hope to know; and we can simply add another to the long tale of priceless gifts for which humanity has to thank some unknown and unhonoured benefactor. Chance pieces of stone, picked up from the surface of the ground, do not promise anything beforehand as available fuel; and the early races of men in Europe can hardly have been put to severe straits for firewood amid the unending primæval forests of the prehistoric period. And yet it is probable that the first man who found out that coal would burn, must have slept with his fathers long before the nations of Western Europe had reached the stage of keeping any voluntary record of their actions. Certain it is that the use of coal as fuel originated among the peoples of the cold and inhospitable West, and not in the Eastern cradle of civilisation; and it is also certain that its properties must have been known for a very long time before its use became at all general. The ancient Britons were acquainted with the use of coal, and the Romans, never too proud to learn from the outer barbarian, acquired the precious secret from them. The Anglo-Saxons employed coal to some extent for domestic purposes; but it was not till the thirteenth century that coal-mining assumed any importance in England; and the other European nations took to the systematic use of coal as fuel at an even later period. In the year 1259, Henry III. granted a charter to the freemen of Newcastle-on-Tyne, allowing them to dig coal; but for a long time it was employed only in the arts and manufactures, and wood continued to be the common domestic fuel. As has been the case with almost every great benefit, the introduction of coal as fuel was stoutly resisted at first, and we find its use prohibited in London in the reign of Edward II. by a royal proclamation, soon discovered to be injurious and foolish, and consequently withdrawn. Jumping from this infantile period of the coal-industry to about the end of last century, Great Britain is found to be raising about ten millions of tons of coal per annum, much of which was exported to foreign countries. Making another leap to the present day, we find the annual "out-put" of coal

in Britain to have reached the enormous amount of over one hundred millions of tons, and to be, on the whole, steadily increasing. We are, therefore, consuming, or in one way or another getting rid of, considerably more than one hundred million cubic yards of the actual stony framework of our country every year; and in so doing we employ the energies of very many thousands of our male population. It is worth our while, then, to know something about the nature and origin of this black combustible, which we exhume from its rocky bed with so much labour and patience, and upon which depends so much of our national prosperity.

If you take a lump of coal out of the coal-scuttle, you find yourself in possession of an irregular lump of black stone, which usually soils the hand that holds it, to a greater or less extent, and which generally presents but one obvious feature—namely, that it clearly consists of thin parallel layers, some of which are usually shiny and glistening, while others are more dull and earthy in appearance. In consequence of this structure, as every one knows who has ever stirred a fire, it is comparatively easy to break up a piece of coal in one direction (the direction corresponding with that of the component layers), but repeated blows from the poker may be vainly used if the refractory lump be attacked in the opposite direction (the direction at right angles to the layers). Now, as before remarked, there is nothing whatever about a piece of coal which would in any way indicate its inflammable nature, and perhaps the first question that we should feel disposed to ask is, *Why* does coal burn?

To answer this question we must call in the help of our chemical friends; but we can get an intelligible reply without dipping very deeply into the theory of combustion. The chemist tells us, then, that coal is composed principally of the elementary substance which is termed *carbon*, and which is seen in its purest form in lamp-black, charcoal, and the wonderfully dissimilar blacklead and diamond. He further tells us that carbon, when raised to a certain temperature, has the strongest desire to unite itself with the gas called *oxygen*, which is present in a large amount in our atmosphere, this union being attended with the production of light and heat, and resulting in the formation of the invisible and poisonous gas which is technically called carbonic-acid gas. When, therefore, we burn a piece of coal in the fire-place, what happens, roughly stated, is (1) that the carbon of the coal enters into direct union with the oxygen of the air, emitting heat and light in so doing, the carbonic-acid gas thus produced escaping up the chimney in an invisible form; and (2) that the earthy and incombustible matter present in greater or less amount in all coals is left in the grate unburned, in the form of ashes and cinders.

Roughly speaking, then, coal consists of from eighty to perhaps ninety-five per cent. of the element carbon, mixed with a small proportion of various mineral substances, which remain as *ash* when the coal is burnt. In addition to these constituents, however, coal contains, locked up in its interstices, a certain amount of inflammable *gas*, varying in quantity in different kinds of coal. The so-called "hard" coals, or "anthracites," contain least of this gas, and are consequently the most stony of all coals, with a shining, jet-like aspect, and burning with a bright-red heat, without flame. Such coal does not readily burn in an open fireplace, but is largely used in furnaces, and in some countries (as in North America) is commonly used as a domestic coal, being burnt in scientifically constructed stoves, and being valued for the intense heat which it gives out. Again, our ordinary household coal in this country contains a comparatively large amount of gas, for which reason it takes fire readily, and burns with a good deal of flame. There are numerous varieties of this kind of coal, but they may be all included under the name of "bituminous" coal. Lastly, we have the stony-looking clean coals, which are usually called "cannel coal." These contain the largest amount of gas of all the coals, and are therefore highly valued and largely used in the manufacture of illuminating gas. The name of "cannel coal" (really "candle" coal) is based upon this, and alludes to the fact that this kind of coal burns with a clear, bright flame.

Having obtained this general notion as to the chemical nature of coal, we may next consider the question as to its origin and mode of formation; and in this inquiry, it will perhaps be an advantage to attack the problem before us in a somewhat roundabout manner. Let us first betake ourselves, then, to one of the great "peat-mosses" which are found so commonly in temperate and moist regions, and which cover such extensive areas in Scotland, Ireland, and the north of England. We may find a "moss" suitable for our purpose high up amongst the hills, or in some low-lying, marshy situation; but in either case the phenomena exhibited are much the same. If we look, namely, at the channel cut by any stream across such a moss, or at any artificial excavation, we find that the ground is

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composed of a substance which near the surface is of light colour and spongy texture, but which at greater depths becomes darker in colour and denser in structure, till at length it becomes quite black and earthy. This substance is what is called "peat," and every one knows that when cut into slabs and dried it makes a very tolerable fuel, and one largely used in some parts of the country. Now, peat is chemically very much the same as a poor kind of coal, for it consists (when deprived of water) of from sixty to ninety per cent. or more of carbon, along with certain earthy impurities, which are left as *ash* when the peat is burnt. The reason why peat is not so good a fuel as coal, is that its texture is so loose that it contains a much smaller amount of carbon in the same bulk, whilst the amount of ash is proportionately larger, and the amount of water contained in it is enormously greater. If peat, however, be subjected to powerful artificial pressure, and have its contained moisture expelled from it, it becomes quite compact and stony, and may be regarded as an artificial coal, from which it differs principally in not containing inflammable gas.

It is clear, then, that peat and coal have much in common with one another, and anything which will explain the mode of formation of the one will throw light upon the origin of the other. Fortunately, there is no difficulty in determining how peat is formed. Peat is undoubtedly composed of the remains of different kinds of plants, and principally of such as delight in moist situations. In our country, peat is mostly formed out of the plants known as "bog-mosses" (*Sphagnum palustre*), which have the curious property of constantly going on growing upwards, throwing out new shoots above, while the lower portion of the stem decays. They thus form a dense mass of vegetation, saturated with water, and constantly rotting below, as its green and growing surface increases in height. Along with the bog-mosses, one can often recognise in peat the leaves or stems of reeds, rushes, and other water-loving plants; and in many cases we find, often at depths of many feet, the trunks or branches of trees, sometimes with numerous erect stumps. This is easily explained by the fact that peat-mosses are often formed upon the site of old forests. By the fall of the trees, either from natural decay or in consequence of storms, the drainage is interfered with, and a swamp is formed, any trees which are still left standing assisting in this process by checking the evaporation of water from the surface. In this way, the growth of bog-mosses and other marsh-inhabiting plants is promoted, and a peat-moss is gradually formed, in which all the fallen trees are soon enveloped.

Such being the origin of peat, there is a reasonable probability that coal is formed after a somewhat similar fashion; and we have the means of raising this probability to an absolute certainty. Before, however, further examining actual coal itself, we shall briefly consider two other kinds of rock, one of which is very like ordinary coal in most respects, whilst the other presents no outward resemblance to it at all. To see the latter in place, we must transport ourselves in imagination to a small, low, densely-wooded promontory on the southern shore of the mighty Lake Huron, which rejoices in the far from euphonious title of "Kettle Point." Long black ledges of rock run out into the blue waters of the lake, and the use of the hammer at once shows us that we have here to deal with one of those soft, muddy rocks, easily splitting into thin layers, which geologists are in the habit of calling "shales." This is not a coal, then? No! it is not a coal; but you can easily satisfy yourselves that it has one of the properties of coal, for it will readily burn, with a bright flame. A closer inspection will show that it is in other respects different from ordinary shales, for the surface of the layers is covered with little round brown specks, smaller than the head of a small pin, though quite visible to the naked eye. To make out these satisfactorily, we must take a chip of the rock, and grind it down till it is so thin that it can be examined by the microscope, when we find that each little brown speck (Fig. 1) is a minute bag—sometimes empty, sometimes filled with still more minute granules.

What, then, are these little bags? The botanist

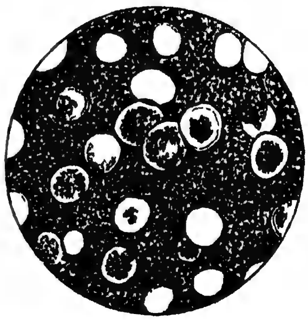

Fig. 1.—A thin Slice of Shale from Kettle Point, Lake Huron, greatly magnified, and showing the little globular Spore-Cases scattered through it.

will tell us at once that they are what we here, speaking roughly, may call the "seeds" of plants resembling our living club-mosses. These seeds,

technically called "spores," contain a great deal of resin in their outer covering, which enables them to resist decay for a long period, and also imparts to them their highly inflammable character. The Kettle Point shale, therefore, is nothing more than an old deposit of mud, charged with the spores of club-mosses, and now hardened into rock; and we can understand its mode of formation quite well by means of an analogous phenomenon which is commonly to be observed in Canada. The wanderer in the Canadian forests is often surprised, namely, to find the margins of the lakes covered with great banks of a yellow powder, looking somewhat like sawdust, only of a finer grain. This powder is really the "pollen" of the fir-trees, which is blown by the wind in great clouds—popularly called "showers of sulphur"—through the illimitable pine-forests, and much of which ultimately falls into the waters of streams and lakes. Extensive accumulations of this powder are driven up by the waves upon the muddy shores of the lakes, and if hardened and consolidated they would form a rock very similar to the combustible shales of Kettle Point.

We may next glance for a moment at the "Lignites" or "brown coals," which are so largely worked for fuel in Germany and Austria, and to a less extent in Britain and in North America. These lignites are found in the form of beds, associated with sandstones, clays, and other rocks—just as beds of coal are found—and though inferior to good coal, they burn quite well. The name of "lignite" (Latin, *lignum*, wood) refers to the fact that they are often obviously and conspicuously composed of regular petrified *wood*, showing the stems, branches, and leaves of trees, quite distinctly. The name of "brown coal," again, is in allusion to the general brown colour of this fuel. Some lignites, however, are quite as black as coal to look at, and could not be distinguished from ordinary coal by the eye alone. That lignites are composed of hardened vegetable matter, as just mentioned, is often so clearly the case, that the most superficial inspection betrays the original fibres of the woody stems composing it crossing each other in all directions. If any doubt could remain upon this point, it is entirely removed by a microscopic examination, which proves them to be almost wholly composed of compressed stems, branches, and other portions of plants. We may therefore regard lignite as a kind of peat, which has been changed into stone by being buried in the earth, and thus subjected to great pressure for long periods of time. At the same time most lignites are of a different origin to peat, for they seem to have been generally formed, to begin with, as accumulations of drifted logs and vegetable *débris* of all sorts, carried down into lakes or seas by rivers, and ultimately covered up with sand or mud. Similar accumulations are known to be in process of formation at the mouths of many of our great rivers at the present day, and when buried by sediment, they will form the "brown coals" of coming epochs.

Let us now return to coal itself, and see, as shortly as possible, what are the data, direct or analogical, which we can command in reasoning as to its origin and mode of formation. In the first place, then, we have the chemical information that coal is principally composed of carbon, in which respect it agrees with peat and lignite, both of which are of undoubted vegetable origin, as well as with wood and the tissues of living plants in general. This fact of itself, therefore, would raise a strong presumption that coal is formed of vegetable matter. In the second place, if we examine coal carefully, even with the unassisted eye, we shall have no difficulty in seeing that certain parts of it have a distinct fibrous structure (in many cases, at any rate), thus so closely resembling charred wood or charcoal, that the name of "mineral charcoal" has actually been given to these portions as a technical term. Moreover, if we had to do much with coal, and were in the habit of examining large quantities of it with any care, we should often find in it portions of the stems and leaves of plants, so well preserved that we could not doubt as to their nature. Fortunately, however, we are not left to rely alone upon our unaided vision, and this is one of the cases in which the microscope affords us invaluable help. Black and opaque as it is, coal can nevertheless be ground down into slices so thin as to be quite transparent, and thus capable of examination by our modern optical instruments. When examined in this way, we find that coal is invariably composed of vegetable matter of one kind or another. Some coals are composed almost wholly of portions of the stems, branches, and leaves of different kinds of plants, and thus may fairly be compared with an intensely consolidated peat. Other coals, again, as shown by Professor Huxley, are principally composed of the minute globular "seeds," or "spores," of plants related to our living club-mosses; and these may be regarded as being essentially of the same nature as the shales of Kettle Point, on Lake Huron, of which we have previously spoken.

We have, thus, direct and incontestable proof that coal is altered and hardened vegetable matter,

and that it is formed out of the remains of ancient plants; but there are some other facts still which require to be considered before we come to a final conclusion as to the method in which it was formed. Coal is found in beds or "seams," varying from perhaps an inch up to sometimes as much as ten or twelve yards in thickness, in the crust of the earth, associated with beds of sandstone, clay, and limestone; and a good deal may be learned by examining its mode of occurrence on a large scale. We cannot here enter into the many interesting facts which are known as to the geographical and geological distribution of coal, but there are one or two points which bear so directly upon the question of the origin of coal that they cannot be omitted. The most important of these is a fact long ago demonstrated by Sir William Logan, and since confirmed by many other observers—namely, that every bed of coal rests upon a bed of clay—now hardened into "shale"—which is penetrated by numerous

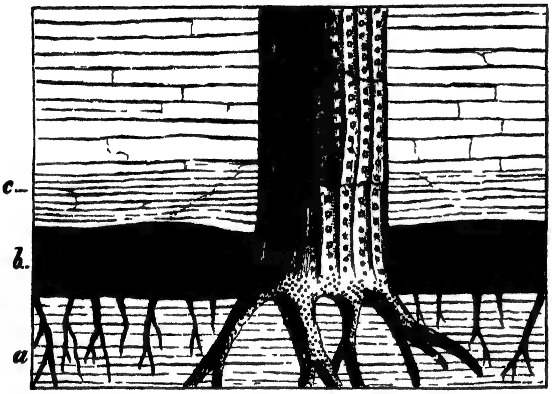


Fig 2.—Diagrammatic View of a Coal-Seam, as seen in the Face of the Working of a Coal-Mine (a) Under-Clay, with roots passing through it; (b) Bed of Coal; (c) "Roof" of the Coal, composed of Sand and Shales, with upright Trunks of Trees passing through it.

perpendicular roots of plants (Fig. 2). This "under-clay," as it is called, is therefore clearly the old soil in which the coal-plants grew. Again, there generally rests upon the seam of coal a bed of shale or sand, which is called the "roof" of the coal, and in which we find innumerable stems and branches of different kinds of plants. Lastly, it is far from uncommon to find in the coal itself, or in the beds which immediately surmount it, the trunks of trees still standing in an upright and vertical position.

The above-mentioned facts render it indubitable that the coals which we burn were not only formed out of the remains of old vegetations, but that they were formed from plants which actually grew in the spot where we now find the coal. Some beds of coal have doubtless been formed, like many of the lignites, out of vegetable matter drifted out into a lake or sea by rivers; but this has been clearly exceptional, and most coals have been unquestionably formed by the uninterrupted growth and decay of successive generations of plants *in place.* In this respect coal is like peat, from which it differs principally in the nature of the plants of which it is composed. Peat is formed mainly by the growth of plants such as the bog-mosses, sedges, and rushes, which not only inhabit moist and comparatively cold situations, but do not in themselves attain any great dimensions. On the other hand, the vegetation which gave rise to the coal was of the most rank and luxuriant character, and is, apparently, indicative of a climate not only moist, but also warm. Thanks to the importance of coal as a fuel, we are now acquainted with some hundreds of plants which lived during the coal period, and which enter more or less largely into the composition of the coal itself, and we are, therefore, not reasoning in the dark when we try to reconstruct for ourselves the vegetation of this wonderful epoch in the history of the world.

It is impossible here to enter into minute details, interesting though they be, as to the nature and structure of these old types of vegetation, and it must be sufficient to say that they belong to four principal types. It the first place, we find a very large number of ferns, some of them comparatively small and herbaceous, resembling our own common ferns (Fig. 3), whilst others were of much larger

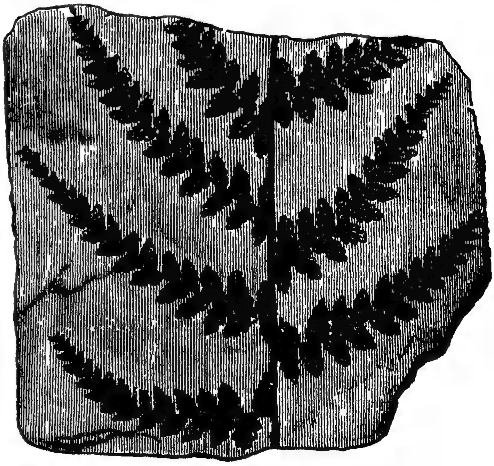

Fig. 3.—Part of the Frond of one of the Ferns of the Coal (*Sphenopteris gracilis*)

dimensions and are to be compared to the giant "tree-ferns" of New Zealand and South America. Secondly, we find a vast number of plants allied to our living club-mosses, but of comparatively gigantic

dimensions, and attaining the size of our ordinary forest trees. The most remarkable of these are the forms known as *Lepidodendron* and *Sigillaria*; and trunks of the latter, in particular, are not uncommonly found in an upright position in the beds associated with the coal-seams. Thirdly, we have the singular plants which are known as *Calamites*, and which are to be regarded as ancient but gigantic representatives of the little horse-tails of the present day. These curious plants, with their long, striated stems, seem to have grown in dense brakes or jungles, and often attained a height of twenty feet or more; few of our living horse-tails exceeding two or three feet in height. Lastly, we meet with a considerable number of true trees, related to our living yew-trees and pines, and sometimes of great size.

Coal, then, may be regarded as essentially composed of the more or less crushed and compressed remains of the leaves, branches, stems, and seeds of different kinds of firs, calamites, ancient club-mosses of the type of *Lepidodendron* and *Sigillaria*, and ferns. The great majority of these plants are "flowerless," and they indicate a dense land vegetation, growing in low, marshy situations, and in a comparatively warm climate. Putting the indications afforded by the plants of the coal together with those afforded by the nature of the "underclay" and the "roof" of each coal-seam, we can form a very good idea of the manner in which an individual bed of coal was produced. Each coal-bed, in fact, represents an old land-surface, probably a vast and nearly level, marshy plain, apparently placed little above high-water mark, such as we may see at the present day covering hundreds of square miles, at the mouths of great rivers like the Mississippi and Ganges. The "underclay," immediately beneath the coal-bed, with its innumerable roots, is the veritable old soil in which grew the tangled jungles of ferns, *Calamites*, *Lepidodendra*, and *Sigillariæ*, which clothed these ancient plains from the margin of the ocean to the far-distant uplands. The actual "coal" itself represents the slow and gradual accumulation, through enormously long periods, of the leaves, branches, trunks, and seeds of this luxuriant vegetation, now hardened and compressed into a mere fraction of its original bulk by the pressure of the rocks above it. Countless generations of plants must have lived and died before the dark and rich vegetable mould could have accumulated to a thickness sufficient to account for the production of even one foot of coal; but at last we must suppose that the old land-surface commenced slowly to sink beneath the sea, and the once verdant plains were gradually covered by the salt water of the ocean. Many of the monarchs of the forest must have fallen where they stood, but others withstood the waves, till their bases were buried by many feet of clay and sand tranquilly deposited around them. The so-called "roof" of the coal thus represents the first accumulation of sediment thrown down upon the nascent coal-bed, and we can readily understand how it should be so rich in the stems and fronds of ferns and other plants, and how it should often be traversed by the upright trunks of trees.

In this way, then, we can explain the method in which a single bed of coal is formed. In a single coal-field, however, we may find fifty to perhaps one hundred beds of coal, lying one above the other, and separated by intervening beds of clay and sand. In this case, we have to suppose that after the formation of the first bed of coal, in the manner above indicated, the old land was again raised above the level of the sea by one of those elevatory movements to which the crust of the earth has been so often locally subjected. Soon, a vegetation as rank and luxuriant as its predecessor flourished on the newly-born plain, and vegetable matter was again accumulated throughout a long period of rest and stability. Then the land once more sank slowly beneath the sea, and sand and mud were once more heaped up over the vegetable *débris* of centuries. In this way a second bed of coal would be formed; and by a repetition of these alternating movements of elevation and depression, affecting great tracts of land raised but little above the sea-level, it is easy to understand how any required number of coal-seams might be formed in succession in the same area.

The vast deposits of fossil fuel which have so largely contributed to place Britain in the first rank of commercial nations, are thus the indurated and compressed fragments of ancient vegetations which lived and died long geological epochs prior to man's first appearance on the earth. The light and heat of our fires are, in strict scientific truth, the "bottled-up sunlight" of past ages. Nor is it easy to over-estimate the amount of time demanded for the accumulation of these great stores of carbon. An eminent chemist has calculated that the dense vegetation of the tropics produces about fifty tons of carbon to the acre of ground in a hundred years; but fifty tons of coal spread evenly over an acre of ground would not make a layer of half an inch in thickness. What, then, are we to think of the

time required for the formation of a seam of coal one yard in thickness, not to speak of such giant seams as the "Ten Yard Coal" of South Staffordshire? There would be something almost painful in the reflection that we are rapidly expending these long stored-up and carefully elaborated accumulations, if we did not, at the same time, know that our very expenditure is the means of returning to the atmosphere the materials out of which new deposits of carbon will ultimately be produced. Even from the black and dusty coal may we thus learn to recognise with admiration some portion of the checks and counterchecks, the balances and compensations, by which the system of nature is preserved in equilibrium; but it would lead us too far to enter upon this subject on the present occasion.

## THE MECHANISM OF THE HEAVENS: HOW COPERNICUS EXPLAINED IT.

By the late Richard A. Proctor.

WHEN the astronomers of old times first recognised the seeming motions of the heavenly bodies, they tried to explain those motions as caused by celestial machinery. The seeming motions of which I speak include, of course, the real motions. But at first men supposed all the motions to be real; so that the machinery they imagined to explain what they saw, was naturally more complicated than was necessary. Then, after a time, they gave up as hopeless the task of explaining the observed motions as due to mechanism of some sort, and tried simply to determine what the actual motions may be. When at length they had learned to distinguish the real motions from those which are apparent only, they found that it was no longer hopeless to explain the real motions as they had once tried to explain the seeming motions; for now the actual motions were found to be comparatively simple. The nature of the celestial mechanism, and the mainspring by which it is driven, were before long determined. Out of the researches which culminated in this achievement, sprang into existence the modern system of physical astronomy. My purpose in the present essay is briefly to consider the history of these researches and the nature of the various steps by which the true theory of the celestial mechanism was reached. But I shall not devote much space to the explanation of the false systems which for a time were accepted by astronomers. I have not, indeed, more space at my disposal than will suffice for the consideration of the steps by which men advanced towards the truth; to trace out their devious wanderings on the track of error, would require much more space and be far less instructive.

In the first place, men noted that at night the star-spangled dome of the heavens is carried round precisely as if it were part of the inside of a great hollow globe, turning round an imaginary axis passing through its centre, the place of the observer. Of course, only one half of this great hollow globe can be seen at once. Such a half is the star-strewn sky seen at any moment on a dark, clear night. If the hollow globe, or what seems like a hollow globe, were turning around a vertical or upright axis, we should always see the same half all the time the turning motion went on. But this is not the case. Here in England, for example, we find that the axis about which the star-strewn globe is turning is inclined, as shown in Fig. 1 by the line O P, O being the place of the observer, and S O N the south-and-north line. In other words, the pole of the heavens, as it is called, is inclined from the point overhead towards the north at the angle Z O P. S W N E represents an imaginary plane above which lies the visible half of the star-strewn globe, the boundary S W N E being what is called the *horizon*. The globe seems to turn around the axis P O P′ in the direction shown by the arrows, quite uniformly and at the rate of one complete rotation or turning in about four minutes less than twenty-four hours. S P′ N represents the unseen half of the star-sphere, P′ in the prolongation of P O being the unseen pole or end of the imaginary axis P O P′, round which the turning seems to take place. It is clear that as the turning proceeds, new stars are continually rising above the half-horizon S E N, while stars which had been visible above the half-horizon S W N are continually passing below it. But a large part of the globe around P is always above the horizon, and a corresponding part round P′ is always below the horizon. Of the circle E e W e′, midway between the

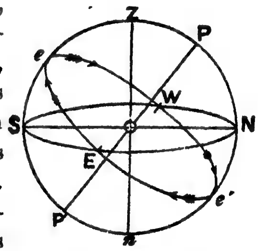


Fig. 1 —Illustrating the Position of the Star-Sphere.

poles P and P′, one half is always above the horizon and one half below. A star on this circle—which is called the celestial equator—rises due east at E and sets due west at W.

By travelling over the earth, men can see the whole of the star-sphere, and from whatever part of the earth its motion is watched, the same uniform turning movement is always perceived. The varying aspect of the star-strewn dome seen from different parts of the earth, is explained by and serves to prove the globe-shape of the earth. But with this point at present we are not concerned. Suffice it, that from whatever part of the earth the vault of the heavens is watched, we see it turning round the same fixed but imaginary axial line, quite uniformly, as if it were carried round by some steadily-driven mechanism.

Next, men noted that although the sun and moon are carried round from east to west, with the star-sphere, they slowly move upon its seeming concavity, in a contrary direction—that is, from west to east. The moon's motion in this direction among the stars can easily be recognised in the course of an hour or two on any clear night. Watching her night after night, we perceive that in about $27\frac{1}{3}$ days she completes a circuit of the star-sphere from west to east, along a certain track, which does not lie midway between the poles like the track E $e$ W $e'$ in Figs. 1 and 2, but is inclined to E $e$ W $e'$. The sun is found also, though not quite by such simple observations, to follow a similar path, once in about $365\frac{1}{4}$ days, or a year. A B C D in Fig. 2 represents his course. One half (A B C) of this path lies above the circle E $e$ W $e'$, that is on the same side of it as P, while the other half (C D A) lies below E $e$ W $e'$, or on the same side as P′. Fig. 3 shows the two circles,

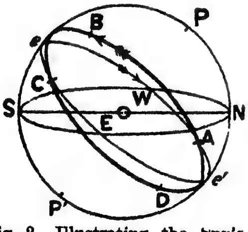


Fig. 2.—Illustrating the Sun's annual Motion round the Star-Sphere.

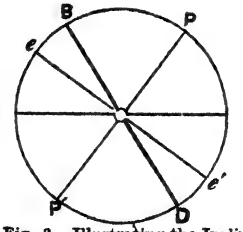


Fig. 3.—Illustrating the Inclination of the Sun's Path to the Polar Axis.

$e$ O $e'$, B O D, as they would appear if seen edgewise—the angle E O $e$ being one of about $23\frac{1}{2}°$ (a right angle, as P O $e$, containing 90°). It must be distinctly borne in mind that while the sun travels, in appearance, along the circle A B C D in the direction shown by the arrow near B, once in a year, this circle, and the sun upon it, and the fixed stars among which it holds a fixed position, are being carried round by that daily motion which I have already described, in the direction shown by the arrow on E $e$ W $e'$ near W. So that Fig. 2 only presents the position which the sun's track A B C D—called the *ecliptic*—has at one particular moment in each day, with respect to the horizon E S W N; the daily turning motion of the star-vault is in fact constantly shifting the position of the circle A B C D with respect to the horizon and the sky above it, though its position among the fixed stars—or rather *because* its position among the fixed stars—remains unchanged. The moon's track is not A B C D—that is, the moon does not travel along the ecliptic. She moves on a path inclined about $5\frac{1}{8}°$ to the ecliptic; and her path among the stars, unlike the sun's, is constantly though slowly changing; but is always inclined to A B C D by about the amount named. At any given time the moon's track is a circle inclined to E $e$ W $e'$, by an angle which has some value between $5\frac{1}{8}°$ added to $23\frac{1}{2}°$, and $5\frac{1}{8}°$ subtracted from $23\frac{1}{2}°$—or between $28\frac{5}{8}°$ and $18\frac{3}{8}°$; and along such a track pursues her course in the direction shown by the arrow near B, making a circuit of the star-sphere once in $27\frac{1}{3}$ days, while all the time the circle she is for the moment travelling in, and she herself, and the more slowly-moving sun, and the fixed stars, are carried round by the daily motion in the direction shown by the arrow near W.

Thus, then, if the observed movements of the heavenly bodies are to be explained by some sort of machinery, carrying those bodies along around the earth fixed in position at the centre, it is necessary that some primary mechanism should carry round the star-vault and the sun and the moon, once a day from east to west, while some subordinate mechanism carries the sun over the star-vault in a slant-circle once a year, and another carries the moon over the star-vault on a varyingly slanted circle once in $27\frac{1}{3}$ days.

But the mechanism of the heavens must be still more complex if it produces all the observed motions, the earth being at rest in the midst of the moving celestial orbs. The sun and the moon are carried, each at its proper rate, round the turning star-vault, and in a direction contrary to its motion. But they always move in that direction, though not with actually uniform motion. A mechanism carrying each of these bodies towards the east at a nearly uniform rate—slightly more quickly, however, in one part of the circuit than in the opposite part—while the sun, moon, and the driving apparatus of each, are carried over together at a perfectly uniform

rate with the star-vault from east to west, would account for the motions thus far described. But when we come to the bodies called planets, and still more when we consider the motions of comets, we find that our mechanical arrangements must be much more complicated.

Five bodies were known to the ancient astronomers which, while resembling the fixed stars somewhat closely in appearance, differ from them in wandering about on the star-vault.

Two of these bodies, named Venus and Mercury, seemed to accompany the sun on his journey round the star-vault. They were not found to travel always the same way with him, however; but would be seen sometimes in advance of him, sometimes behind him, sometimes travelling in the same direction, sometimes in the opposite, though always travelling *on the whole* in the same way, their movements from west to east, called their advancing motion, always exceeding in range their movements from east to west. Mercury was found to range far less widely from the sun than Venus. For about 58 days Mercury is on one side—say in advance of—the sun, then for about 58 days he is in the rear of the sun. Not that he can be seen all the time, for owing to the sun's brightness Mercury can only be seen when, in these excursions (so to speak), he gets farthest in advance and farthest in the rear of the sun—that is, for a few days in the middle of these successive periods of about 58 days. Venus, on the other hand, is in advance of the sun during about 292 days, and then is in the rear of the sun for a similar time. She can be seen during the greater part of each of these periods, being only lost for a short time when passing the sun each way Not only is she much brighter than Mercury, when seen under similar conditions, but she ranges nearly twice as far on both sides of the sun as Mercury does. Neither Mercury nor Venus travels along the sun's track, however, but range widely from it both above and below, besides ranging in advance and

Fig. 4.—A Part of Mercury's Track; the dotted Line being a Part of the Sun's Course.

in the rear of the steadily advancing sun. Figs. 4 and 5 illustrate the nature of these planets' movements. Only it is to be noticed that the loops and bendings are constantly varying in shape. Mercury, for instance, does not always travel round a loop as shown in Fig. 4, but sometimes on an open, twisted path, like that of Venus in Fig. 5; or on a path part looped, part twisted. Sometimes the loop or twisting lies below, sometimes above, the track of general advance. Sometimes the range of the loop or twisting is greater, sometimes less, though always within certain limits for each of these two planets.

Besides Mercury and Venus, which travel in paths thus peculiarly related to the sun's, are other three planets, named Mars, Jupiter, and Saturn, which also follow looped and otherwise contorted tracks, but do not attend in that special manner on the sun which we notice in the case of Mercury and Venus.

Mars traverses a loop or twisting having such a range (compared with that of the loops of Mercury and Venus shown in Figs. 4 and 5) as is indicated in Fig. 6, travelling backwards in the

Fig 5.—A Part of Venus's Track; the dotted Line being a Part of the Sun's Course.

middle part of the loop, but advancingly in the parts preceding and following the shorter backward track, as shown by the arrows. Then Mars continues to advance till he has made a complete circuit of the stellar vault and about one-seventh more, when he retrogrades through a short arc

Fig 6.—A Part of Mars's Track; the dotted Line being Part of the Ecliptic.

as before, making another loop or twisting. Then he advances again through about a circuit and a seventh of the star-vault, and makes another loop; and so on continually. The interval between the times when he is at the middle of successive loops is about 780 days, on the average, Mars traversing the entire circuit of the heavens in about 687 days. Although he circuits the star-vault in this leisurely way, so that the sun is always gaining on him, and thus Mars is not always, like Venus

and Mercury, in the same part of the heavens as the sun, yet the motion of Mars is in another way related to the sun's. For it is noticed that he always crosses the middle of his backward swoop when exactly opposite the sun, so that Mars is then seen due south at midnight, when, of course, the unseen sun lies due north below the horizon.

Jupiter and Saturn behave somewhat differently. Each sweeps out loops or twistings, travelling backwards (see Figs. 7 and 8) when in the middle of the shorter arc, so as to advance on the whole; but both these planets advance far more slowly than Mars. Thus Jupiter, after traversing his loop, advances through only about a twelfth of the circuit of the stellar heavens before traversing the next loop; then through about a twelfth of the circuit before traversing another; and so on continually. The interval between the times when he is at the middle of successive loops, called the "synodic period," is about 399 days, or little more than half the corresponding interval in the case of Mars; but in the interval Jupiter has traversed less than a twelfth of the circuit of the stellar heavens; whereas Mars, in his corresponding interval or synodic period, traverses a circuit and a seventh. Jupiter, in fact, does not complete the entire circuit of the star-vault in less than 4,332$\frac{3}{5}$ days, or about 11 years 315 days. This is his *sidereal* period.


Fig. 7.—Two Loops of Jupiter's Path. (The dotted Line is the Ecliptic.)

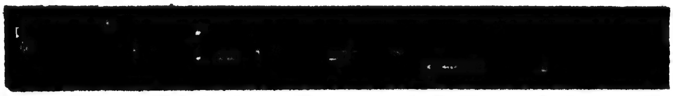
Fig. 8 – Three Loops of Saturn's Path. (The dotted Line is the Ecliptic.)

Saturn moves still more slowly. The interval of time between his passage through successive loops is, indeed, only about 378 days, or three weeks less than Jupiter's synodic period. But in this interval he completes only about a 29th part of the circuit of the heavens. His sidereal period thus amounts to 10,759$\frac{1}{5}$ days, or about 29 years 167 days.

Both Saturn and Jupiter exhibit in their motions the same peculiar relation to the sun already described in the case of Mars, being always exactly opposite to the sun when traversing the middle of their short retrograde arcs. Moreover, it is observed that each of the three planets is at this time at its brightest.

All these motions have to be explained by any mechanism devised to account for the movements of the heavenly bodies about the earth, supposed to be at rest.

Speaking generally, and only at such length as space conveniently permits, we give the following as the views held by ancient astronomers as to the mechanism by which these effects were brought about.

They supposed the star-sphere, or rather the spherical shell in or on which the stars were thought to be set, turned round on the polar axis once in a sidereal day, or about four minutes less than a solar day, as the outermost of a set of seven spherical shells carrying the five planets and the sun and moon, but carrying round these spheres along with it.

The earth was supposed to be at the centre of the star-sphere; but the other spheres within it were not supposed to be quite concentric with it; so that the slightly-varying motions of the sun and moon, and the slightly-varying rate of general advance of the five planets, might be accounted for. The sphere (by which word "spherical shell" is to be understood throughout) carrying Saturn was supposed to be next the star-sphere; next, the sphere of Jupiter; then, in order, those of Mars, the Sun, Venus, Mercury, and the Moon. The spheres of the sun and moon were supposed to have a simple turning motion from west to east in a year and a month respectively, the motion being really uniform, but appearing to vary because of the eccentricity of the earth's position within each sphere. But the spheres of the five planets were supposed each to carry round a smaller sphere round which the planet travelled; so that the apparent motion of each planet was made up of the motion of the planet round the smaller sphere, and of this smaller sphere round the larger one; and by assigning suitable rates to these two motions, and suitable proportions to the larger and smaller sphere, it was found possible to account for the varying apparent motions of each planet—that is, for what Milton has called

> "Their wand'ring course, now high, now low, then hid,
> Progressive, retrograde, or standing still."

So far as the movements of the planets, indeed, were concerned, the effect of these spheres within spheres, and their movements, would be the same as though, instead of being carried round in spheres, as described, each planet were carried uniformly round in a small circle whose centre was carried

uniformly round in the same direction in a larger one. The effect of such conjoined motions may easily be seen to correspond in general with the peculiarities of planetary motion.

Suppose, for instance, that a planet is moving in a circle (*a b c d*, Fig. 9) round the point C, which is itself advancing in a circle (A C B)—the movements being in the direction shown by the arrow-heads—around

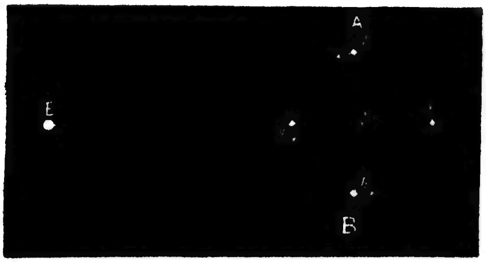


Fig. 9.—Illustrating the Ptolemaic Explanation of Planetary Motions.

the earth at E, either as centre, or somewhat eccentrically placed to account for varying rate of general planetary advance. Thus it is obvious that if the planet travel more quickly in the circle *a b c d* than its centre travels in the circle A C B, it will seem when at *a* to travel backwards. When at *b*, it will appear to be advancing at the rate at which the centre C is advancing, and at some point between *a* and *b* it must, therefore, have changed from retrogression to advance. At *c* the planet will seem to advance, and much more rapidly than it seemed to retrograde when at *a*, for its retrogression at *a* was due only to the excess of its own motion, in circle *a b c d*, over the motion of the centre of this circle in the circle A C B; but its advance at *c* is due to the combined advance of the planet in the circle *a b c d*, and of this circle's centre in the circle A C B. At *d* the planet still seems to be advancing, though now only (as when at *b*) with the advancing motion of the centre C in the circle A C B. Lastly, as, when it arrives again at *a* in its smaller circle, it will again be retrograding, there must be some point between *d* and *a* where the advance merged into retrogradation, or where the planet seemed for the moment to be stationary. There has been, on the whole, an advance, because the circle *a b c d*, and with it the point *a*, has been carried steadily onwards all the time. There has also been a change of distance from E, between least distance E *a* and the greatest distance E *c*. Moreover, as observation shows each planet to be brightest or to *seem* nearest when in the middle of its backward arc, so we see that according to this explanation the planet really is at its nearest to the earth when at such a point as *a*, where the middle of its retrogression occurs. Lastly, by having the plane of *a b c d* slightly inclined to the plane of A C B, the range of the planet on each side of the ecliptic can be explained. In order to account for the fact that, when situated, as at *a*, in the middle of its arc of retrogradation, the planet is always either opposite the sun, as in the case of Mars, Jupiter, and Saturn, or in the same direction as the sun in the case of Mercury and Venus, all that is necessary is that the motion in *a b c d* should be completed in one year exactly. Thus, to take the case of a planet like Jupiter, if when the planet is at *a* (Fig. 10) the sun is at S, then when the planet has gone

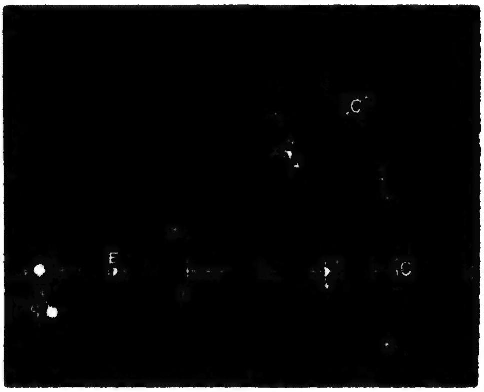


Fig 10.—Illustrating the Ptolemaic Theory.

once round its circuit and so much more as brings it to *a'*, C' being the position of its centre of motion and C' *a'* E straight, the sun will obviously have gone once round and so much more as brings him to S' on C' E produced—that is, he will be opposite to the planet at *a'*. And it can easily be shown that similar reasoning will explain the seeming motions of planets like Mercury and Venus with reference to the sun.

The theory was ingenious, but artificial. It required not merely a double motion for each planet to account for the alternating planetary motions, but also that the double motion of each planet should keep exact time, so to speak, with the motion of the sun, which yet belonged to an entirely different sphere. Then, while each planet had its two spheres and its double set of motions, the sun having its sphere keeping time with the motions of each of the lesser planetary spheres, and while the moon had also a sphere to itself, all these spheres turning from west to east, they all shared in some mysterious way the rotation of the

star-sphere from east to west once in the sidereal day. When it was further found that the planets have many minor peculiarities of motion which even this complex machinery could not explain without continual additions; when astronomers found that they must

> "build, unbuild, contrive
> To save appearances, and gird the sphere
> With centric and eccentric scribbled o'er
> Cycle and epicycle, orb in orb;"

men began to seek for a simpler explanation, if such might be found.

The system of Copernicus went far to remove all these difficulties. According to it the rotation of the star-sphere, carrying with it all the other spheres, though not preventing their proper motions, was at once done away with by regarding the earth as turning on her axis from west to east once in a sidereal day, and thus causing in stars, sun, moon, and planets, an apparent motion from east to west in the same time. An immense mass of complexity was thrown off by this change alone, which is usually little noticed in our treatises on astronomy. But of course the distinguishing feature of the Copernican theory is the explanation it affords of the apparent motions of the sun, the moon, and the planets, and specially of the planetary loops. Of all the bodies which seemed to travel around the earth as a centre, Copernicus left one only as really so travelling—the moon. The sun he regarded as at rest, and explained his apparent motion round the earth once in a year as caused by the real motion of the earth round him once in a year. It needs no demonstration to prove that if an observer is carried round a fixed body so steadily as to be unconscious of his motion, the fixed body will *seem* to be carried around him in the same time. So far all was simple enough. What remains to be shown is only a little less obvious (though, obvious as it is, it had never been recognised till Copernicus pointed it out), and was what gave to the theory of Copernicus its chief claim to acceptance. It was this. If the earth travels round the sun once in a year, and each planet travels round the sun at due distance once in the period which had formerly been assigned to the planet's so-called sphere, all the chief characteristics of planetary motion are at once accounted for. Instead of requiring that each planet shall travel round in a circle whose centre travels in a circle round the earth, Copernicus showed that it is only necessary for each planet travelling in a circle round the sun to be viewed from the earth, which is itself travelling in a circle round him. So viewed, it would advance, become stationary, retrograde, become stationary, advance again, and so on, tracing out loop after loop, precisely as each planet actually does.

To prove and to explain that the apparent motion is *precisely* the same whether a planet is carried round in the way illustrated in Fig. 9, or whether it is carried around the sun (S, Fig. 10) in a circle (A C B), of the same size as A B C, Fig. 9, and observed from the earth carried round S in a circle (*a b c d*) of the same size as *a b c d*, Fig. 9—the periods in each circle being respectively the same—are not altogether


Fig. 11.—Illustrating the Copernican Explanation of Planetary Motions

suited to these columns. But a proof of the general proposition that a planet will alternately advance and retrograde, advancing on the whole, as the planets actually do, may be readily given. Thus, suppose the earth at *a* (Fig. 11) travelling more quickly round the circle *a b c* than a planet outside her path at C travels round his circular track A C B. Then the planet at C seems to be travelling backwards, because the earth at *a*, with her more rapid motion (the two motions being for the moment on parallel lines), leaves the planet behind. Next let the earth be at *b*, where a line (C *b*) touches the circle *a b c d*, the planet being supposed to be at C. (The reader will remember that we are now only considering the nature of the apparent motions when the earth and planet are in different *relative* positions, so that we need not consider the varying position of the outer planet on A C B.) Then, since the earth is at the moment moving directly from the planet, the only apparent motion of the planet is that due to its own advance in its track A C B; thus the planet seems to be advancing. When the earth has some intermediate position, then, between *a* and *b*, the planet's retrograde motion changes into advance. When the earth is as at *c*, the planet as at C, then since the earth is moving in one direction (shown by the arrow-head), and the planet in the opposite direction, the planet

necessarily seems to be moving with greater velocity in this last-named direction, the earth's motion adding (*apparently*) to the planet's. Thus at this time the planet seems to advance most rapidly. When the earth is as at *d*, the planet at C seems to be advancing, but with its own motion only. And lastly, when the earth is again as at *a*, the planet being as at C, the planet seems to be retrograding; so that when the earth had some intermediate relative position on *d a*, the planet seemed at rest. Of course, in reality as the planet has been advancing all this time, instead of the two bodies being as at *a* and C on the straight line S *a* C, they are as at *a′* B on the straight line S *a′* B. The earth has thus gone round an arc such as *a b c d a′*. More than a year has in fact elapsed (as we note in the actual motions of Mars, Jupiter, and Saturn), between the successive retrogradations of the outer planet. Again, when the planet is at C, the earth at *a*, and the sun at S, the planet, already shown to be in the middle of its arc of retrogradation, is opposite to the sun at S, and is also at its nearest to the earth, and therefore at its brightest, precisely as observation shows it.

It would be easy to extend this demonstration to the case of the planets Mercury and Venus, which according to the Copernican theory travel within the path of the earth. But in reality it is unnecessary. For the proof just given for the case of an outer planet (called technically a *superior* planet) applies also to the case of an inner planet (called an *inferior* planet).* For at whatever point on the star-sphere one planet seems to be as seen from another, this last as seen from the former must of necessity appear at the exactly opposite point in the star-vault. So that in whatever way an outer planet seems to move as seen from an inner planet, in the same way precisely does the inner planet seem to move as seen from the outer, only on the opposite side of the star-sphere. Thus, as we have seen that a superior planet seen from an inferior one (when both are travelling round the sun, the inner the more quickly) seems alternately to advance and to retrograde, advancing on the whole, so an inferior planet seen from a superior planet, seems to advance and to retrograde, advancing on the whole. And the fact that at the middle of an inferior planet's retrograde arc the planet is in conjunction with the sun, is also explained in this way; for whereas from *a* the planet at C (Fig. 10) seems to be opposite the sun, at the middle of its retrograde arc, a planet at *a* seen from a superior planet at C is in the same direction (C *a* S) as the sun, or is lost in his light at the middle of its arc of retrogradation.

In this way, assigning to the sun the central position, to the planets Mercury and Venus orbits within the earth's, Mercury's nearest to the sun, while outside the earth's track came the orbits of Mars, Jupiter, and Saturn, each planet travelling more slowly the farther lay its track from the sun, Copernicus accounted for all the leading characteristics of the motions of the sun and planets. The moon alone was left travelling around the earth as centre. He explained the daily motion of sun, moon, planets, and the perfect steadiness and uniformity of the motion of the star-sphere, by assigning to the earth, as she circuits once a year round the sun, a perfectly uniform motion of rotation on her axis.

In another paper I propose to show in what respects the theory of Copernicus was deficient, how Kepler perfected the explanation of the celestial motions, and how Newton showed the nature of the mechanism to which these motions are due.

* These words, "superior" and "inferior"—literally, "higher" and "lower"—bear reference in reality to the old theory of the planetary spheres; for the sphere of an outer planet was outside, and therefore, as viewed from the earth, it ranged *above* the sphere of an inner planet.

## HOW PLANTS FEED.

BY ROBERT BROWN, M.A., PH.D., F.L.S., ETC.

A VERY unscientific glance at a flowering plant shows the ordinary observer that the flower is intended for the perpetuation of the species by forming the seeds. The leaves, we have already seen, constitute the lungs and the stomachs. The stem is often wanting, and therefore cannot be absolutely essential; while the roots, it is obvious, fix the plant in the soil: that is to say, when the plant is fixed in the soil; for some of the orchid order send their roots down from the limbs of trees, round which the plant clings, to find nourishment in the moist air; while others, like the ordinary

duckweed of our "green-mantled pools," float about on the surface of the water, in which the roots hang. However, these are exceptions. Let us take a plant which comes within the rule. Any one will do. Here is a chrysanthemum. We see the roots are composed of short, twine-like fibres, arising from around a central and thicker portion, tapering away to a point, and which, though a true root, is the downward prolongation of the stem. To use the language of the botanist, the root is the "descending" and the stem the "ascending axis" of the plant. Here, again, is a turnip, in which the root is bulbous; and, finally, among the shrubs which the gardener is rooting up, preparatory to commencing his spring operations, we may find roots branched and branched again, until they end in delicate fibres, which, after all, are the real

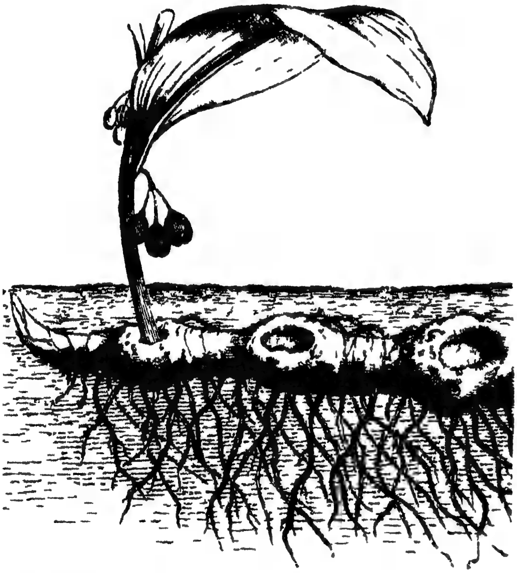

Fig 1.—Rhizome, Root-Stock, or underground Stem of Solomon's Seal (*Polygonatum*), showing the Scars or "Seals" left by the Decay of the old Branches.

roots, as these fibres wander through the soil, dig in among the stones and rocks, and thus search far and near for the food of the plant. It is perfectly evident that the roots anchor the plant. It is almost equally self-evident that they also suck up out of the soil the food of the vegetable which appears above it. Cut off the roots, and the plant dies, unless others sprout out to take their place. If the roots are injured, the plant becomes sickly, just as an animal does if its appetite fails—or, in other words, is not in good working order. For we shall find presently that the roots feed the plant, if the leaves digest that food, and that they really exercise a discriminating power in the selection of what is good for them, and what they like, and in rejecting what is not to their taste or wholesome for the constitution of the vegetable, of which they are humble but all important functionaries.

Every part of a plant which is underground is not, however, a root. The thick, root-like portion of the iris or water-flag, which creeps horizontally under the ground, is really a stem: the roots are only the portions which hang from it. So is the corresponding portion of "Solomon's seal" (Fig. 1); and so are the tubers of potatoes, which are in reality —as we may have occasion by-and-by to find out for ourselves—shortened and thickened branches, the "eyes" in which are really the same as the buds of the above-ground branches. Let us, therefore, see if we cannot detect any difference between the root and stem. We soon notice that the root has no true bark, while the enveloping skin is very thin, and possesses few or none of the pores or openings which are found on most of the green portions of the plant. We have already seen them scattered abundantly over the leaves, and have there figured them (p. 21). As they constitute important organs in plant life, we engrave one of them on a still larger scale than has been already drawn (Fig. 2). Next we find that the root has no true pith, and no buds, and is generally covered more or less abundantly with delicate hairs. It will also vary much according to the soil in which it is grown. Take, for instance, the "non-such," which is everywhere so common in our pastures. Here we find the length of the root out of all proportion to the length of the stem. In sandy soil, the root has to be very active in searching for nourishment, just as people who live in poor countries have to be more industrious, in order to gain a livelihood, than those inhabiting rich ones. Hence the roots of these plants—like the bent-grass and the sedges —will stretch very far. Again, the same root will in different soils have different characters. In rich ground it will be short; in poor ground, long. Lucerne-roots will sometimes acquire a length of thirty feet; while those of an ordinary-sized ash will not unfrequently attain ninety feet, in their efforts to find food for the tree. What the plant feeds on, how the roots grow, and how

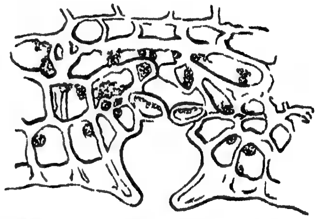

Fig 2.—Leaf-Pore (*Stoma*), highly magnified.

the materials which they pump up out of the soil enable the whole plant to increase in size, we shall consider by-and-by.

Meantime, it is necessary only to consider the structure of the root so far as will enable us to ascertain how it exercises its functions. Seek out, therefore, the most delicate fibrillet of one of these roots. Examine it with a magnifying-glass, then with a low power of the microscope; and, last of all, slice it delicately with a razor—or as delicately as you can, for this is an art which requires practice and skill—one of the tips, and something

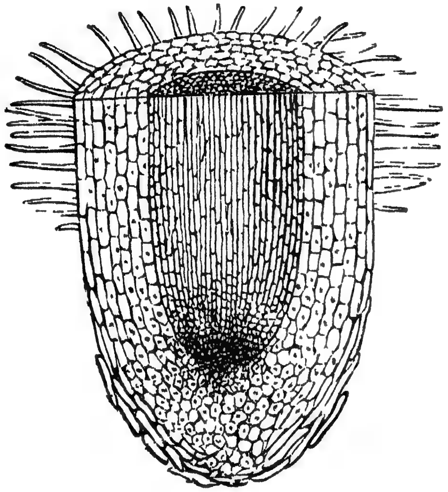

Fig. 3.—Tip of a Rootlet as seen under the Microscope.

like what is portrayed in Fig. 3 will, after some trouble, be seen.

The delicate tip is, like all parts of plants when in their earliest stage, composed of the little bladders or cells which we have already spoken of when discussing the structure of the leaf (p. 21). These cells are firmer on the exterior than in the interior, where they begin to assume the characteristics of the pith. Around the lower portion of the root-tip is a kind of cap or sheath of flattened cells, and at the lowest portion of all a number of loose dead cells, which have served their function, and are being thrown off. They now serve no purpose in the economy of plant life, and are simply filled with air, though at one time they were believed to absorb the nourishment from the soil. Higher up on the figure will be seen a number of very delicate hairs projecting from the side of the rootlet. These hairs are, like all vegetable hairs, simply cells, elongated, instead of being more or less globular, as in other portions of the plant. These hairs require only sharp eyesight, or, at best, a magnifying-glass, to be seen. The other parts can be studied through the microscope only; and the root-sheath is not readily detected in all plants. In the so-called "screw-pine," however, it is remarkably well developed. When the roots of this tree dry and contract, the root-cap or sheath is sometimes seen covering it like a long hat. It may also be well seen in some of the fir order, and in the ordinary duckweed it is easily seen without the aid of artificial means. It there protects the tender floating root from the shock of foreign bodies, and against the attack of minute animals (Fig. 4). Such is the general structure of the root, which differs only from that of the stem in a few not very important particulars, which can perhaps be best considered when we have occasion to investigate how a plant grows, and how the food sucked up by the roots nourishes the plant, and increases its bodily structure. The next question to consider is, What are the uses of the roots? These, we have already seen, must primarily be to fix the plant in the soil, and to draw up the food of the plant from the same source. Indeed, the one function must necessarily be dependent on the other. Without plants being fixed in the soil, the nutriment could never be extracted from it by them. But is not the rose of Jericho—so called because it is not a rose at all, but a plant belonging to the cabbage and turnip order—an exception? In reality it is not, for it gets uprooted only when it dies away; and such also will be found to be the case with the other supposed exceptions. It will be seen that the position of a root buried in the soil enables it to escape the vicissitudes of climate to which the rest of the plant is subject—the summer's heat and the winter's cold—and thus assists in preserving the life of the plant. The root is the first portion of the plant which appears when the seeds burst. Until the rootlet can fix itself in the soil, the young plant cannot commence

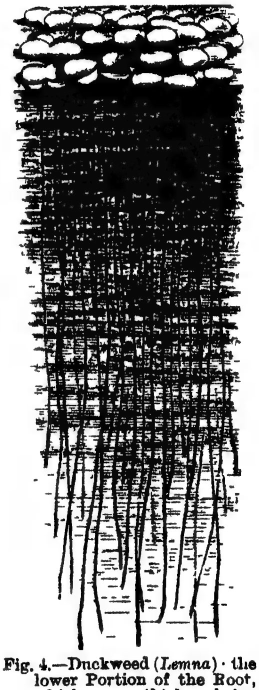

Fig. 4.—Duckweed (*Lemna*): the lower Portion of the Root, which seems thicker, being the *Ampulla* or Sheath.

life for itself. In the same manner, a settler in a new country, before he commences to make the woods ring with his axe-blows, or even to roof his hut, makes provision for his bodily sustenance. Then, after his flour and his bacon are stored in his tent, his house roofed in, and his household goods set up, he brings his family to the scene of action, and commences life in earnest. And so it is with the vegetable. It first makes provision for sustaining its life, and then it puts forth its other organs. Finally, after being assured of sustenance, it blossoms, produces seed, and then multiplies and increases. How necessary, even in an early stage of the plant existence, is the soil, in order to temper the climate to it, is evident from the following fact:—On the table-lands of the higher Colorado, the heat is very great. During the greater portion of the year no rain and very little dew fall. Hence the soil for some inches below the surface is arid, hot, and parched. But the Moqui Indians raise, notwithstanding, good crops of maize by planting the seed at a depth of about a foot. There it is beyond the influence of the sun's rays. The young rootlet, when sprouting out from the seed, is not burnt up, and it finds in the soil enough of food, until the plant gets stronger, and can bear the sun's heat.

It therefore follows that the plant is rooted in the soil in order to extract nourishment from it. If the root is cut off, the plant dies. All the young and delicate portions of the root are engaged in absorbing nourishment from the soil, and cease to do so only when these parts get impervious to moisture by the formation of a corky layer in them, and by the skin of the root otherwise thickening. But the root-hairs seem to play the most important part in drawing up the liquid nourishment from the soil. We see this in a variety of ways. For instance, when the upper parts of the root get thickened, so that no nourishment can enter, then the hairs fall off, but are renewed on the younger and thinner-skinned portions of the plant. All the nutriment of a plant must be in the form of a liquid or a gas. Nothing solid can enter into it through the walls of these delicate cells. Dissolve in a glass of water some of the materials which constitute the food of plants, and then colour it with a pinch of gunpowder. The plant will grow, develop its leaves, and even flower, and produce its seeds in this liquid soil. Indeed, large plants of maize have been thus grown and seeded. Then take out the plant, and analyse what remains of the water. It will be found first that the plant has absorbed some of the substances dissolved in the water, but none of those not dissolved. For example, the minute particles of charcoal which coloured the water being incapable of being dissolved, but only "held in suspension" by the water, have been rejected. Another fact, and quite as important as this, will be noticed: this is, that the plant has not taken up all the substances which have been dissolved in the water, nor has it taken those which it has absorbed all in the same proportion. One substance it has greedily devoured, another sparingly, a third in scarcely appreciable quantities, and a fourth it has left untouched. Supposing that we had grown another species of plant in exactly the same solution, we should find a different result. Thus, as in the first case, not one atom of solid matter had passed into the body of the plant. But the substances in solution would be found to be unequally absorbed. Perhaps some of those which the first plant had rejected would be greedily swallowed; others, very little; or, again, that of which only an unappreciable amount was devoured, would by the second plant have been taken up in considerable quantities. This shows that roots—acting on behalf of plants—have a "selective power." That means that all plants do not require the same kind of nourishment, and that the root seems to have a kind of instinctive knowledge of what is best for the nutrition of this plant.

There is one little difficulty which stands in the way of accepting this alluring doctrine of the instinctive character of roots, and that is, that they will absorb poisons which kill the plant. However, it is just possible that these substances so deaden or destroy the delicate tissues of the root as to render their power of selection inert. Be that as it may, there can be no doubt of the selective power of roots. Indeed, this faculty lies at the bottom of much of our agricultural science and legislation. On it is founded the theory of the "rotation" of crops, and that standing grievance of the farmer, the clause by which he is bound in his lease not to grow two wheat-crops in succession, not to sell straw, hay, roots, or, in fact, any fodder-crop off the farm, and so on; the object being not to exhaust the soil, and to compel the cultivator to put into it, in the shape of manure, the substances which he has previously extracted from it, by aid of the crops grown on it. For instance, a soil which would not support a crop of potatoes for two successive seasons, would be quite good for oats, potatoes, or grass in three successive seasons, simply because what the oats did not care for the potatoes would eagerly feed

on, and what the potatoes and oats had spurned would be food enough for the grass. We thus see that manuring is just feeding the soil, and that deep ploughing is only turning up the soil as yet unreached by the roots, and therefore still full of food for them. We also allow a field to lie "fallow," or ploughed but uncropped, in order that the yet undissolved food-elements in the soil may get time to go into the condition necessary for feeding the plant—viz., either into the form of liquid or gas. In this we also see the explanation of such familiar phrases as that a soil is "good" or "bad," "poor" or "rich," "good grass land" or "fair wheat land." Indeed, in the selective power of roots lie consequences deeper than at first sight seem evident. The selective power of roots is in reality the primary cause why nations spread naturally over the world. They must have land to cultivate their crops; and before artificial methods of renewing the fertility of the soil were discovered, it got "exhausted" or "worn out," and the agricultural people had to seek newer lands, which as yet lay in all their virgin richness.

The Civil War in America was due to the selective power of roots and ignorance of vegetable physiology. Politics aside, this is no paradox. Tobacco and cotton are both exhausting crops. They require many substances to nourish them, and a great deal of all of them. Hence they "wear out" the soil. For miles and miles along the banks of the Mississippi there are worn-out estates of the thriftless planters. For a time this did not matter: land was plentiful and the soil virgin. But by-and-by the land which could be easily brought under cultivation for the staple crops got scarce. Then the planters wished to remove to the newer States further west, and to carry along with them their "peculiar institution." This was objected to by the free States, and then commenced that quarrel which culminated in four years of bloodshed, and the end of slavery on the North American Continent. If the Southerners had known about manures—or, rather, chosen to apply their knowledge as they have to do now—Appomatox Court House might still have been an obscure spot in Virginia, and "the late unpleasantness" an unwritten volume of the history of the Great Republic.

Roots can perform their functions under strange circumstances. Water-plants have been seen growing at the sides of boiling springs, and even in them; while in the island of Tanna, ground near a volcano, though of the temperature of 210° Fahr., is covered with flowers.

But roots perform another function necessary to the life of a plant. Grow a plant with its roots in a glass of water. Take care not to stir that water, so as to allow the atmospheric air to enter; then cover its surface with a film of oil, so as to prevent the access of any more air. For a time the plant will grow well enough, but after a time it appears sickly, and then just on that part of the stem above the surface of the oil will appear small knobs which after a time will develop into roots, and these roots will descend, just as did the ordinary ones, at the base of the stem. This may not always happen; but we are stating no supposititious case, but one which has more than once been observed. The reason of these roots thus springing out to supplement the others in the water seems to be owing to the fact that the roots have exhausted the air in the water, and the oil preventing the access of the atmospheric air, the plant has been compelled to throw out others above the surface of the oil, in order to perform this necessary function of respiration; for the roots not only absorb nourishment—they also breathe, and air they must have, equally with the leaves, though not to so great or important an extent. We see this in many familiar cases. For instance, roots seek out and fill up drains in their vicinity, the search for air being, though not the sole cause for this habit, yet the chief one. Again, that plants breathe is shown by the fact that if roots are plunged into hydrogen, nitrogen, and, above all, carbonic-acid gas (p. 22), the plant will die in a few days. This likewise explains why in cities trees often die when their roots are subjected to the influence of soil impregnated with ordinary coal-gas escaping from the neighbouring pipes, or from entering sewers where various noxious gases are accumulating or emanating. This function of roots also gives amateur gardeners a hint. Horticulture is simply the art of keeping in health and multiplying artificially certain plants. Now, this can be done only by knowing the laws of plant life, just as health will be destroyed if the laws regulating animal life be infringed. Amateur gardeners are often grossly ignorant of the first principles of vegetable physiology, just as professional ones are; but in the case of the latter experience makes up for the want of theory or scientific knowledge. When a citizen obtains a piece of ground, his enthusiasm to make a *rus in urbe* knows no bounds. He is seized with a wilder desire "to garden" than ever possessed Mr. Briggs

"to hunt." And this horticultural zeal almost invariably takes the form of picking up every stone out of the soil, and of raking the surface. The result is that after the first few heavy falls of rain the soil gets caked, and in dry weather almost impervious to slight showers, and altogether to sufficient air. Now, if the stones had been allowed to remain, they would have kept the earth loose, and prevented the finely-powdered mould from becoming soddened. This also shows the advantage of frequently loosening the soil round plants, so that air as well as moisture may more easily have access to the roots. For the same reason, trees should not be surrounded by pavement, or, plants grown in glazed pots, if they are to be kept in good health.

We have spoken of the roots which spring from the plant grown in improperly aërated water. These were what are called "adventitious roots," or, literally, roots "which come to the assistance" of the others. They occur regularly in some plants, and are the roots which spring when cuttings—such as those of roses or of willows—are placed in the soil. But they commonly spring from growing plants in moist, warm, shady places, such as the depths of tropical forests. In Madeira and Teneriffe, for instance, the Canary laurel sends out during the autumn a great number of adventitious or air roots, which surround the stem, and grow to the thickness of the finger. In the following autumn they die and fall to the ground, giving place to new ones. Indian corn, oats, valerian, grape-vine, and other plants subject to the combined action of heat, moisture, and shade, will often produce these air-roots. Probably they collect moisture from the air, and also assist the imperfect respiration of the ordinary earth-roots of the plant. The adventitious roots of the screw-pine surround the trunk as if it were supported by a number of props. But the most remarkable, and probably one of the best-known cases of adventitious roots, is afforded by the famous Indian fig, or banyan-tree (Fig. 5). On the banks of the Nerbuddah, in India, is a gigantic tree of this species, which tradition affirms sheltered Alexander

Fig. 5.—View of the Banyan-Tree (*Ficus Indica*), showing Adventitious Roots

the Great. The adventitious roots are so large as to appear like trunks springing from both stem and branches: so that this tree is composed of 350 large trunks and more than 3,000 smaller ones. At one time, before part of it was carried away by floods, it was capable—so runs the tale—of sheltering 10,000 men, but even yet 7,000 people could repose under its shade. The mangrove (Fig 6) is another shrub, or tree, which has these aërial roots well developed. In this case the main root will sometimes decay, and the plant be entirely dependent on the adventitious roots. The mangrove is especially characteristic of the low, swampy, feverish shores of various inter-tropical countries, and the tendency in it to send out roots in the air is shown even in the earliest condition of the plant. The seed begins to germinate while the fruit is yet attached to the parent branch; and often the young rootlet grows to the length of a foot or more before the fruit falls into the mud. In some tropical countries when the adventitious roots are cut off others will spring out, and in some plants—the vine, for example—if the root gets injured, adventitious ones will often appear. In old willows it is a common subject of observation that when the stem becomes more or less decayed, adventitious roots will be produced in the upper part of the trunk, as if it were attempting to obtain fresh supplies through a more vigorous and healthy channel. It is said that the yellow water-lily—common in ponds and lakes in this country—casts its old roots and supplies their place by producing new ones, just as the Canary laurel does (p. 101)

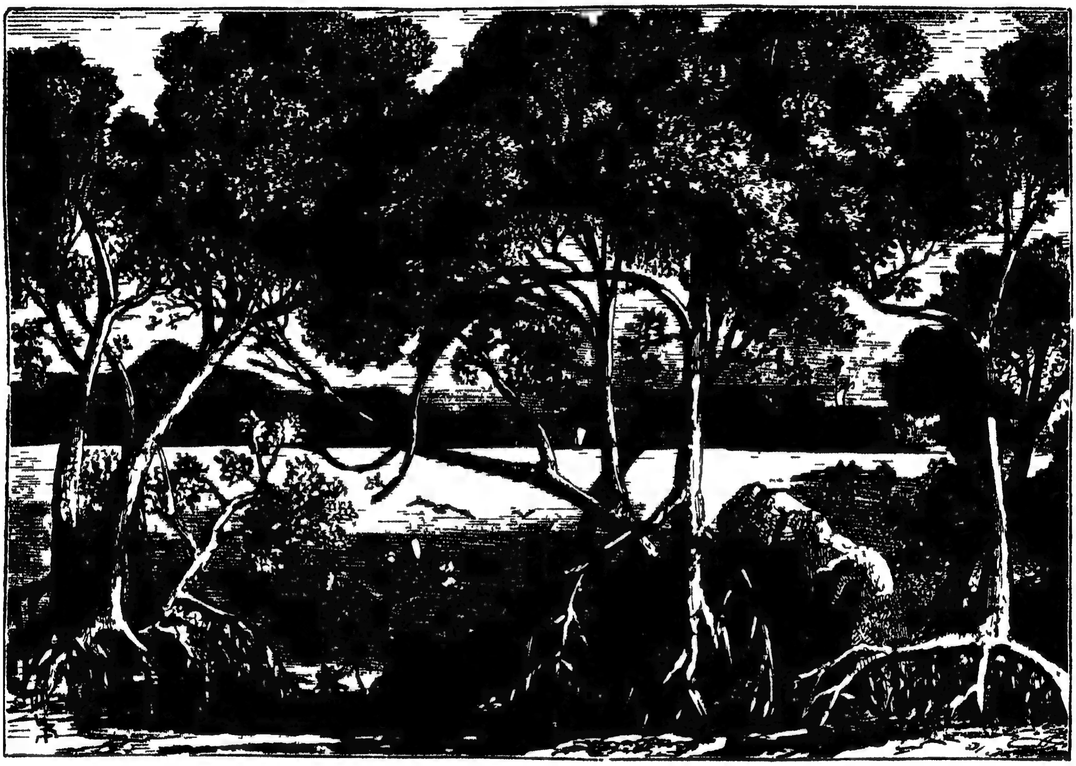

FIG. 6—MANGROVE (*Rhizophora*), SHOWING THE ADVENTITIOUS ROOTS WHICH SUPPORT THE TREE AFTER THE ORIGINAL ROOT HAS DIED AWAY.

The root is, however, something more than a mere organ of fixation, nutrition, or respiration. We are all familiar with the thickened root of the carrot and turnip, in which are stored up supplies of starch and sugar, utilised as food for man and beast. It is, however, quite unnecessary to say that the plants did not store up their supplies for any such end. The real purpose can be detected if we allow a turnip-field to remain undisturbed, as is the case when it is wished to obtain the seeds. During the first winter the plants have their bulbous roots—the turnips of agriculture—fresh and full of "flesh." By next autumn the plants have flowered and produced seed, and the once well-filled roots are mere shells. All the starch,

sugar, and juices have been sucked out of them to support the plant's exhaustive process of flowering. The farmer, however, by removing the bulbous roots from the soil in the autumn and winter, preserves for the use of his stock the nutrient substances which would otherwise have gone in the ensuing autumn to support the growth of flower and seed. In like manner the starch, as in the "tubercles" or bulbous roots of orchids, goes to support the plant. In the hog-plum these tubercles contain upwards of a pint of clear liquid, and in the Kalahari desert—according to Livingstone—the liquid stored up in the roots of such plants serves an important use among the Bojesmen who inhabit that arid waste. In various water-plants—such as the bladder-wort (*Utricularia*)—some of the leaves are transformed into little floats filled with air, so as to buoy the plant on the surface of the water; but in certain other aquatic plants of the genus *Jussiæa* this rôle is sustained by the roots, some of which are transformed into swimming bladders of a more or less cylindrical shape.

Last of all it is believed that some plants use the roots to throw off some substances which are useless to the plant, and which thence become noxious to the soil. Thus, it is commonly said that the darnel grass and flea-bane are hurtful if grown in wheat-fields, that the creeping thistle is "antipathetic" to oats, the purple spurge and field scabious to flax, the corn spurry to buckwheat, and so with a long list of other plants in cultivation. Again, on the contrary, it is believed that wheat is a good crop to precede beans or peas, from the idea that wheat has sent out from its roots substances which are beneficial to the life of these plants. There is, however, no real grounds for the belief that roots "excrete" substances. Indeed, even supposing that these "excretions" could remain in the soil long without undergoing chemical change, it is difficult, as the writer has remarked in another place, to see "how many plants could grow on the same field if this were true; or how, if a plant sends out noxious substances into the soil, great tracts of country could be covered with the same species; how forests could be composed of different species; or, indeed, how an isolated tree could flourish for hundreds of years in a soil impregnated with its own excretions. Each plant has, however, the power of making the soil less suited for others of the same species, or of other species of the same family which succeed it, though improving it for species of another family. Oaks, for example, render the soil more suitable for firs, and *vice versâ*." This is the real explanation of it. Thus, leguminous crops (beans, peas, tares) prosper after cereals (wheat, barley, oats), simply because the first order of plants derive their nitrogen from the air, and the other from the earth; the one *exhausts*, the other *improves* the soil. Still there is no use denying that roots exercise a certain chemical influence on certain hard bodies. A root of the cat-mint has been seen growing through the midst of a peach-stone, while—among many similar instances—it may be mentioned that the roots of some plants have a corroding influence on marble. This looks as if an acid had been given off: but we really know nothing about it. We have thus seen that the roots are at once the feeders and the anchors of the plant—as well as its underground lungs, the floats of some water species, and the storehouses against an evil day of many others. Its functions are known thus far; but a knowledge of the use of the root, as well as its structure and development, are—in common with similar information regarding the leaf—the keys which open the gateways to vast fields of knowledge. With this knowledge, the reader may not be wise: without, he cannot but be ignorant.

# EMPTY SPACE.

By William Ackroyd.

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THERE is a plaything called a "sucker," consisting of a circular piece of soft leather, to the centre of which is attached a foot or two of twine. It works in this way: the leather soaked with water is pressed against the surface of a smooth stone; the string is then pulled gently, and the leather with the adhering stone is lifted up from the ground. Some who read these lines may recollect that in their early days the mark of a good sucker was the great weight it would lift; yet no boy, unless perhaps a Faraday *in embryo*, asked himself why the sucker adhered to the stone:

he rested content with the feat accomplished, or the fun derived from it. It may now appear to many passing strange, but it is none the less a fact, that the reply is intimately connected with the consideration of *empty space*, and in dealing with this subject we shall incidentally answer this and other equally curious questions.

When we have poured all the water from a decanter, we are accustomed to speak of the vessel as empty. In reality, however, it contains air, and not until every particle of this air has been removed and none allowed to re-enter can we strictly speak of the void within as empty space. Such a condition is an ideal state which the physicist may constantly strive after and get nearer and nearer to, but never reach. It will be understood then that by empty space we mean those approaches to it which may be obtained by means of the air-pump, with various accessory devices Let us therefore at once ascertain how to produce empty space, and having obtained either it, or an approximation to it, we may then study its peculiarities. Steam occupies 1,650 times more room than an equal weight of water. If we could therefore fill a vessel with steam, and then convert this steam into water, we should practically obtain empty space, for the room which before was taken up by steam would now be void. The reader will see this more forcibly by taking note of what Fig. 1 is intended to teach.

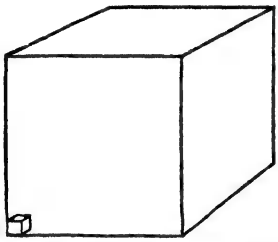


Fig. 1.—Illustrating the Relation between the Volume of Water and Steam

The large cube represents the space taken up by a quantity of steam, and the little cube (*a*) in the corner the room occupied by the water formed when all this steam is condensed This idea being grasped, we may now in the endeavour to obtain the desired result take a tin can, with only one opening, from which proceeds a tube with a tap attached; put in a small quantity of water, and boil it (Fig. 2). When all the water is converted into steam, remove the heating apparatus, and at the same time turn the stop-cock in order to prevent the ingress of cold air. If the steam be then condensed quickly by sprinkling the outside of the can with cold water, a curious thing happens. The can is suddenly crushed in. As we see nothing in contact with it competent to produce the effect, we are led to infer it is done by the pressure of some invisible agent. So far as the production of empty space is concerned, the experiment will plainly not answer our purpose; but we have learnt that an external something presses heavily on the vessel—a fact which may be of future use to us.

Our next attempt shall be of a different nature. When we pour water down a tube, it passes through and falls to the ground, or into a vessel placed to receive it. Take a tube open only at one end instead of both, and lay it down in a trough of water. It fills directly. Now keeping the open end under water, lift up the closed end until the tube is perpendicular. Since water falls through empty tubes, it ought to fall down this closed one, and thus leave an empty space extending from the top of the tube to the surface of the water in the trough. We try the experiment. Not a particle of water falls, and we have therefore to register another failure. We repeat the experiment several times with a like result, using at one time a glass jar, and at another a glass tumbler. This effect was so unexpected that we pause to think over it for a while. An idea flashes upon us, and in a very short time we have vaguely connected cause and effect. May it not be that the pressure of that external and invisible agent which caused our first failure is here at work pressing up the water into the glass vessels we have used? The suggestion is worth following up, and presents itself with extra force when we call to mind a geological phenomenon precisely analogous. Down in a coal-mine the collier in his burrowings has to leave pillars of coal untouched in order that they may support the heavy roof. Sometimes a very annoying

Fig. 2 —Illustrating the Pressure of the Air on an empty Vessel.

Sandstone.
Shale.
Coal.
Shale

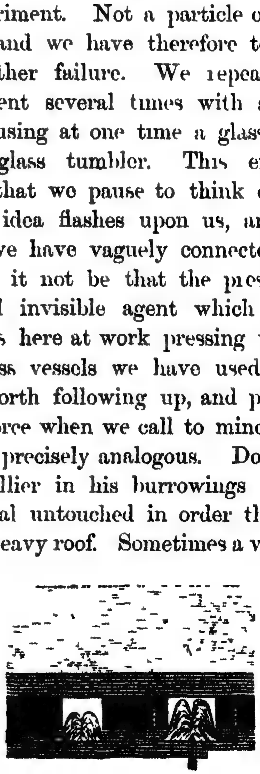

Fig 3 —Section of a Newcastle Coal-Pit. (*Adapted after Buddel.*)

thing happens. The pressure of the great mass of overlying rock on these pillars is so considerable that the soft flooring is forced up and completely

fills the passage (Fig. 3). It takes place very slowly, but none the less surely. First a slight bend of the floor is observed; the bend becomes more decided; then it cracks, and in the meantime has nearly reached the roof. Let us minutely compare what here happens with the experiment that puzzles us.

First take another jar or tumbler, and instead of placing it in the trough to fill with water, bring it on to the water's surface with its mouth downwards. The water does not rise in the vessel, because it contains air. In our former experiment, therefore, the water plainly adhered to the inside of the jar because there was no air to keep it out when the invisible agent pressed it up. Figs. 3 and 4 will now exhibit the analogy in its full force. Fig. 3 represents the conditions which obtain in a pit, Fig. 4 all we see in our experiment. The soft floor in Fig. 3 answers to the water in Fig. 4, and the gallery of the pit to the interior of the jar. In the one case the cavity is surrounded by rock, in the other by the invisible atmosphere. Just, then, as the rock forces up the floor in the one case, so may the atmosphere force up the water in the other, and such a hypothesis or supposition would be quite consistent with what we have hitherto observed. If we see as we proceed that our hypothesis harmonises still more facts, it will become of some value, and will not only account for those facts, but also indicate others which on searching for we ought to find. The compass is not more useful to the mariner than hypothesis to the scientific man. Let us therefore follow this one we have framed whither it leads us.

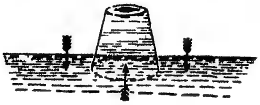

Fig. 4.—Inverted Tumbler full of Water.

When Messrs. Glaisher and Coxwell made their remarkable ascent in a balloon, to the height of 29,000 feet, the air was so thin—*i.e.*, there was so little of it in a cubic foot compared with the quantity in that volume at the earth's surface—that Mr. Glaisher fainted. We have reason to believe it grows thinner and thinner the higher we go; hence there is probably a limit to the atmosphere. Astronomers think that this limit is somewhere about 200 miles from the surface of the earth. It is a column of air reaching from this great height to the place where we stand that probably exerts the pressure of which we have been speaking. We may now make exact experiments in a manner which will be best understood after a little consideration of some introductory examples. Suppose we had three rods, one of glass, another of lead, and a third of cork, all of the same area in cross section, and perfectly round. Let the rod of cork be 40 inches long. If we now place this column of cork on one of the pans of a balance, we shall find that we have to chip down the lead to a length of 1 inch to make it counterpoise the cork; and to make the glass balance the cork we have to grind it down to a length of 4 inches. It is hardly necessary to mention that the 4 inches of glass will just counterpoise the 1 inch of lead, since they each equal the 40 inches of cork in weight (Fig. 5). Now if we were dealing with liquids we should have no need to use a weigh-scale, for the liquids would balance themselves. Take a glass tube bent into the shape of a U, and pour into one limb mercury and into the other water (A, Fig. 6). Like the columns of lead, glass, and cork, we find here that the columns of mercury and water are of unequal lengths. Measure the length of the water-column $a'$ $b'$, and likewise that of the mercury $a$ $b$; and measure both from the same level, the bottom of the water. The column of water is thirteen and a half times longer than that of mercury, but they are both of the same weight, because they balance each other. Now we come to the point. In a syphon barometer (B, Fig. 6) the column of mercury $a$ $b$ is balanced by a column of air extending from $a'$ upwards to the place which would represent the limit of the atmosphere were our diagram large enough. The column of mercury is about 30 inches high, and be it noted there is no air in the upper part $b$ $c$ of the closed limb, or the mercury could not be forced so high. We have just seen that a column of water balancing one of mercury is, roughly speaking, thirteen times longer; consequently the atmosphere which balances 30 inches of mercury will balance thirteen times 30 inches, or 33 feet, of water, and water as a matter of fact will rise no higher than 33 feet in a

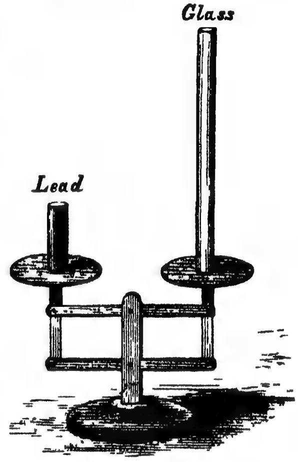


Fig. 5.—Lead and Glass balancing each other.

water-pump when the air is sucked out by working the piston.

One hundred and fifty years B.C., Ctesibius of Alexandria, by inventing the common pump utilised the principle we have arrived at without knowing it. We generally find, however, that in these matters Nature is a long way ahead of us, and in the present instance certain of the cuttle-fishes, squids, &c., are endowed with means for obtaining sustenance based on this same principle. Here is an account of the exploit of one of these monsters taken from a scientific contemporary: "Victoria, Vancouver Island, September 27th, 1877.—An Indian woman while bathing was pulled beneath the surface of the water by an octopus or devil-fish, and drowned. The body was discovered the following day in the bottom of the bay in the embrace of the monster. Indians dived down and with their knives severed the tentacles of the octopus and rescued the body. This is the first recorded instance of death from such a cause in this locality, but there have been several narrow escapes."

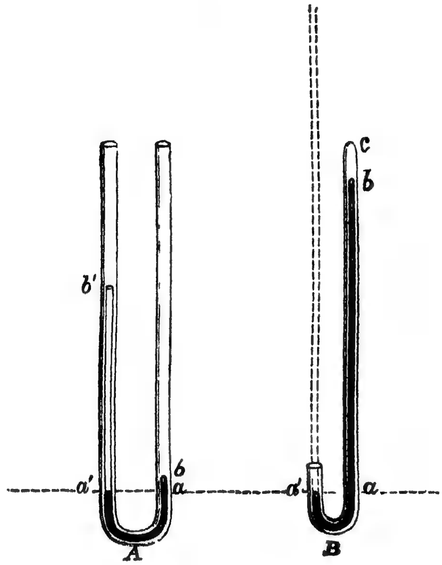


Fig. 6.—(A) A long Column of Water balancing a small Column of Mercury; (B) a long Column of *Air* balancing a small Column of Mercury (Syphon Barometer).

The arms of the octopus are supplied with fleshy suckers, which when once attached to its victim are with difficulty got rid of. In explaining their nature the reader will see that they work exactly like the plaything described at the commencement. Each fleshy sucker is a stalked cup, from the bottom of which rises a plug that nearly fills it. By the action of muscles this plug can be withdrawn. When therefore the margins of the cup are applied to any surface, and the plug is drawn back, a partial empty space is produced, and the sucker adheres to the surface by atmospheric pressure. Fig. 7, A, is the sucker of a squid that I have roughly sketched. A word here about the leather sucker will not be out of place. When we pull the string the middle portion of the leather is drawn upwards; a partial vacuum or empty space is created at *s* (B, Fig. 7), and external pressure prevents the separation of the leather and the stone, just as the fleshy disc and the substance it is placed against are held together in the animal sucker we have been describing.

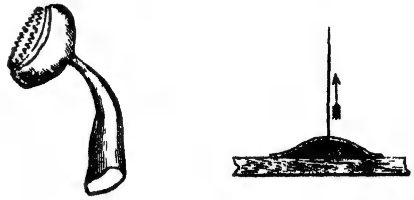

Fig. 7.—(A) Sucker of a Squid; (B) Section of a Leather Sucker.

In the scorpion, too, the same principle is applied, for, according to Professor Huxley, there is behind its mouth a bag-like cavity which it can open and squeeze to at pleasure. Its motion, in fact, is just like that of an indiarubber ball, which may be squeezed together by the pressure of the hand, and will expand in virtue of its elasticity when that pressure is removed. When the scorpion applies its mouth to the wound it has made on its prey, this bag is gradually opened, and the juices rush in to fill up the empty space; when the bag closes it forces the contents down its throat. The process is of course repeated again and again until the animal is sated. Hence we see that the blood-sucking of a scorpion and the successful working of a certain plaything, the rise of water in a pump and the grasping of its prey by the octopus, are all based on the same principle—a principle which so far has prevented us from obtaining even an approximation to empty space. Before resuming our search for it, it may be well that we should tell the story of how the foregoing facts have been ascertained.

In the early part of the seventeenth century flourished a man whose fame became world-wide. In the bigoted and superstitious age in which he lived he shone a star of the first magnitude, and the splendour of his light has not been dimmed even by the rise of other suns, nor yet by the obscuring effect of the ever-receding past. This man, named Galileo Galilei, was the inventor of a

telescope with which he swept the heavens and ascertained many of those wonders that have since thrown observers into raptures and poets into song. He discovered that most important property of swinging bodies, which enables us to regulate our clocks, and to him are due many other great discoveries which have enriched our knowledge. It so chanced that when he was growing old the Grand Duke of Tuscany had a difficulty. For certain fountains, his pumps were required to raise the water some 40 or 50 feet. But howsoever perfect the pistons of these pumps were made, it was found the water could not be drawn so high. According to Galileo's measurement, the water ascended about 32 feet, and as he had previously learnt by experiment that air has weight, he readily conceived that the column of water was maintained at this height by a similar column of air of indefinite length. The ideas of the master being doubtless dominant in the mind of the disciple, it happened one year after Galileo's death that Torricelli, a pupil of his, bethought him of a neat method of demonstrating this point. Torricelli reasoned thus: "Mercury is about thirteen times heavier than water, therefore a column of mercury equivalent to 32 feet of water would be a thirteenth of this in length, or about $2\frac{1}{2}$ feet. If then I take a tube about 40 inches long, and sealed at one end, then, filling it to the brim with mercury, close the opening with my finger and bring it under the surface of mercury in a basin, upon taking my finger away the mercury-column ought to fall until it measures $2\frac{1}{2}$ feet long from its top to the surface of the mercury in the basin." His experiment was a success, for his reasoning was correct; and thus originated the barometer. Some five years after this, such a barometer was carried up a mountain at the suggestion of Pascal, the celebrated Frenchman, who argued that if this mercury-column be sustained by a column of air, then as we ascend a mountain it ought to become less and less in length. Expectation was again realised, and in 1804, when Gay Lussac made his balloon-ascent, he found at a height of 23,000 feet that the column of mercury was only $12\frac{1}{2}$ inches long (p. 30).

It appears, then, that in any device we may adopt for procuring empty space, there must be no liquid forming even the smallest part of the boundary of that empty space, or it will soon inevitably fill it. We must set about, then, and seek some method different from those we have already tried, or at least some modification of them. In problems of this kind we may often receive ideas from the study of Nature's devices, and in the present instance the sucker of the octopus suggests the employment of a tube with an air-tight plug, and for regulating the air-currents we bethink us of the action of the valves in blood-veins. It is requisite that blood should flow one way in these veins; they are therefore provided with pouch-like folds of the inner wall of the vein, and so long as the blood runs the right way, as at A, no resistance is offered to its flow, but when any tendency is manifested to run the wrong way, this very action of the blood lifts up the valve to bar the passage, as at B.

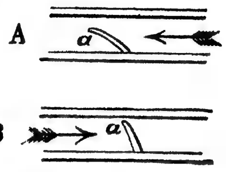

Fig. 8.—Action of the Valves of the Veins.

With a movable and air-tight plug and a suitable disposition of valves many kinds of pumps might therefore be devised. We will describe one of the simplest. On a smooth and perfectly flat plate a bell-jar rests (Fig. 9). In the middle of the plate there is an aperture from which a pipe leads to the pump. The portion of the apparatus *a b c* is generally called the "receiver." The tube from the receiver enters the barrel of the pump at *f*; at *p* we have an air-tight piston which will move up to *d* and back again to *e*. There is a valve at v opening outwards. Now when the piston is pulled up to *e*, it forces the air in this portion of the barrel through the valve, and at the same time the air in the receiver and remainder of the barrel has expanded to fill up the increased space. When the piston is pushed back, no air enters through the valve, as the latter is kept shut by the weight of the atmosphere outside; and when the piston gets to *d*, more air from the receiver rushes

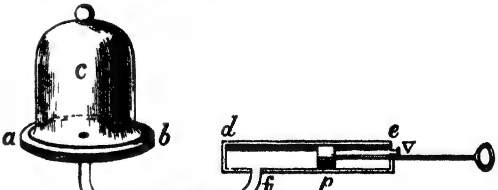

Fig. 9.—To illustrate the Action of the Air-Pump.

into the barrel, and at the next back-stroke is carried forwards through the valve. Mark that the valve permits of the air passing only one way—from within to without. Repeated working of the piston to and fro reduces the air in the receiver *c* to such an extent that it would not support animal life; still there are billions of molecules of gas in

it which cannot be removed by pumping alone: this small residuum of gas being incompetent to raise the valve when the piston approaches it. The pump we have described is known as Grove's.

In the experiment of Torricelli, already gone into, there is an empty space at the top of the barometer-tube, which is generally known as the Torricellian vacuum, and we can readily obtain such an empty space by means of the Sprengel's pump. There are no valves in this pump, and its manner of working is exceedingly simple. Mercury flows in a continuous stream in one of the limbs of a T tube until it reaches the crossing; it then proceeds forward in a broken stream, or as a series of mercury-plugs, each of which carries a small quantity of air before it, this air coming from the remaining limb. If therefore a vessel be attached to this limb, and the joint be made air-tight, such a vessel will perform the function of a receiver, and will soon be nearly exhausted of air, if we keep the mercury flowing.

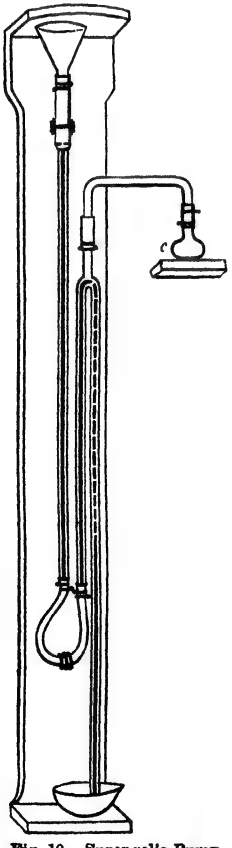

Fig. 10.—Sprengel's Pump at Work.

The vessel *c* is, after awhile, emptied of air to such an extent that I have often seen it shivered into a thousand pieces when formed of thin glass, thus furnishing another example of the external pressure of the atmosphere. Fig. 10 is a sketch of a Sprengel's pump at work.

In passing, we may observe that we have it now in our power to prove by direct experiment that the air has weight, and thus to place beyond dispute all we have said about its exerting pressure. Employ a vessel with a stop-cock in the neck, and when exhausted by the Sprengel pump, turn the tap to prevent the ingress of air. Now weigh. After weighing, turn the cock and let in air. Weigh again. At this second weighing it will be found to be heavier than at the first, the difference being due to the weight of the air admitted.

| | |
|---|---|
| Second weighing . . . | 2645·464 grains |
| First weighing . . . | 2625·500 grains |
| Difference . . | 19·964 grains |

We measure the capacity of the flask, and find it holds a very little over a pint and three-quarters. We can now say then that a pint and three-quarters of air weighs about 19·964 grains. This experiment was first tried in 1650, by Otto von Guericke, of Magdeburg, and may be said to be the first of that series of gas-weighings which form the very foundations of our modern chemistry.

Now that we can get a *vacuum* or empty space, we are in a position to study some of its peculiarities. First, then, we are struck by the clink of the mercury as it falls down the discharge-tube in a Sprengel's pump that has been working for some time. To what is this sound due? for we certainly did not hear it while there was yet much air in the pump. Let us modify the experiment by trying to reproduce it with some liquid other than the mercury. We make an instrument consisting of a glass tube with a little water in it, and sealed up in such a manner that we have a vacuum within. Upon shaking this tube, the water inside produces the metallic sound, hence the instrument is known as the "water-hammer." We will here describe how to make a water-hammer, so that the reader may try the experiment for himself (Fig. 11). A little dexterity in glass-blowing is required. Take a piece of glass tubing, and blow a bulb at one end (A). Fill the bulb with water, and draw out the upper part of the tube to a fine constriction, so that the bore at this particular part will not much exceed in width the thickness of a pin. Attach to the end a piece of indiarubber tubing that can readily be opened or shut by a clip (B). Now boil the water, and whilst the tube is full of steam take it away from the lamp, and at the same instant tighten the clip. Then seal up the thin part of the tube with a sharp and small blow-pipe flame (C). When the steam condenses, there is a vacuum in the tube, and the water gives that metallic click when shaken from which the instrument derives its name. The

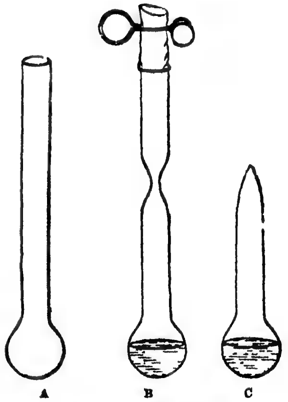

Fig. 11.—Stages in the Making of a Water-Hammer.

phenomenon is thus generally explained: The noise accompanying any collision between two bodies is much lessened—nay, may be entirely removed—by the interposition of a soft cushion. Under ordinary circumstances, the air confined between the particles of water acts like such a buffer, and when we remove it by boiling, and prevent it from entering again by having the water in a vacuum, then the water-particles can jingle together freely. The sound is thus transmitted to the glass envelope, thence to the air, and finally to the ear.

Sound cannot be produced in a vacuum. If we place a musical box within the receiver of an air-pump, and let it rest on wadding, no matter how loudly it plays, we cannot hear it when the receiver is properly exhausted. Had we, however, not placed wadding under it, but allowed it to be in direct contact with the metal plate of the receiver, under such a condition we should hear the box, for the instrument is then connected with the exterior by means of the plate just as the water in a "water-hammer" is by the glass containing-tube.

The relations of empty space to life are rather interesting. Since animals require air to breathe, it is evident they would die at once if placed in a perfect vacuum; and in vacua such as we can produce with an air-pump, backboned animals soon die, but those that have not backbones live for several days. The much longer persistence of life in the one case than in the other would lead us to suppose that the organisation of one was much better fitted for life in empty space than that of the other. A comparison, then, will be instructive. Now in backboned animals the breathing apparatus is confined to a limited portion of the body, and consequently the gases stored up in the parts remote from this region would, in virtue of their great expansibility when pressure is removed, cause the animal to swell out as soon as ever the receiver was exhausted, and death would probably result from rupture of the finer vessels of the body just as

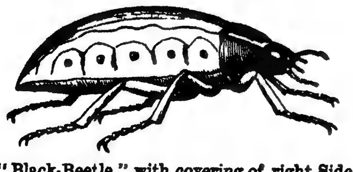

Fig. 12.—"Black-Beetle," with covering of right Side removed the Air-Holes (*Stigmata*)

soon as from deprivation of air. Insects, on the other hand, have their skeletal parts on the outside of the body—an arrangement which would resist such a swelling until equality of pressure within and without was restored; moreover, their breathing apparatus ramifies throughout the whole body. If one side of the covering of a "black-beetle" be removed, on the skin beneath small apertures will be seen (Fig. 12). These little holes lead to a complicated system of air-passages which are found in every part (Fig. 13). The communication between external and internal air is therefore so perfect that difference of pressure soon rights itself, and there is besides the greatest available amount of surface exposed to air. The build of the insect is therefore more fitted for life in empty space than that of the backboned animal. Hence, if we accept the belief of many astronomers that the atmosphere of the moon is like the air in an exhausted receiver, we can readily fancy that its inhabitants, if there be any, will partake more of the nature of cockroaches than of backboned animals.

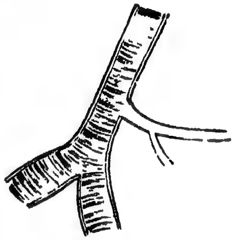

Fig. 13.—Air-Tubes (*Tracheæ*) of a Cockroach.

We all have some idea of what an electric spark is (p. 45), for we see it on the grand scale in the lightning's flash, and on the small scale when we rub the hairs of a cat's back the wrong way in a dark room. In the laboratory readier methods are employed, by which one can produce the spark at pleasure. One of these is by means of a big bobbin-like instrument, known as the Ruhmkorff's coil (D), introduced into the circuit of a galvanic battery (Fig. 15). Such a spark when it passes through a vacuum exhibits very striking effects. The vessel (C) is lit up with a beautiful light, which differs with each gas we have in it, air giving a fiery red to feeble violet light; carbonic acid, a green; and nitrogen, orange-yellow. These colours likewise vary with the degree of exhaustion, and with the dimensions of the containing-vessel. The light, moreover, presents a peculiar layer-like appearance, the alternate strata being much brighter than the rest, and for this reason the phenomenon has been termed the *stratification of the electric light.*

In polar latitudes, discharges of electricity in the higher and rarer regions of the air give rise to the aurora borealis, and our puny laboratory experiments are here exceeded a million-fold. Nor do our experiments in this direction approach the natural phenomenon in beauty, the great arc of ever-varying light appearing like a luminous curtain of red, green, and yellow. By examining

coloured lights with an instrument called the "spectroscope" scientific men can generally tell the nature of the substance producing the light. Such an examination of the aurora borealis has shown

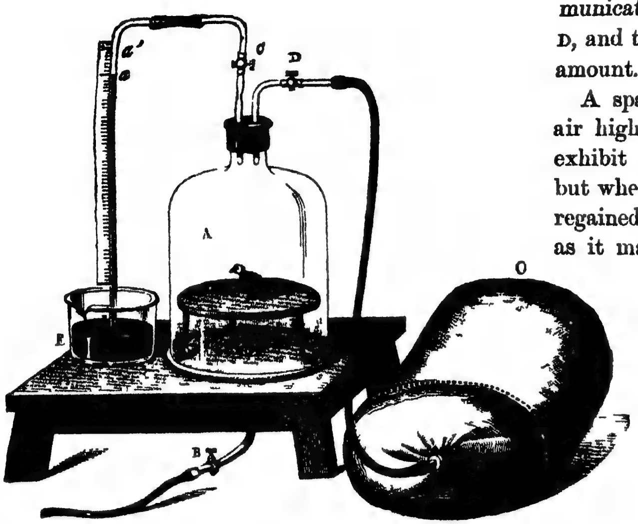

Fig 14 – Apparatus used in Bert's Physiological Experiments.

that nitrogen—one of the gases which go to form air—is present, so that we may regard this phenomenon as a grand electrical experiment taking place in that great vacuum or empty space which aëronauts can never hope to reach.

Fig. 14 represents an experiment made by M. Paul Bert, which is interesting as having a direct bearing upon this subject.

The air we breathe consists of oxygen and nitrogen; it is the former which is the essential constituent, as it purifies the blood, and in so doing keeps up the animal heat. Now, the chief feature of M. Bert's experiments is that of giving animals small doses of oxygen, as he maintains that some of the bad effects experienced by aeronauts, when in the higher regions of the atmosphere, are due to the comparative lack of oxygen. We will describe the means he employed to ascertain this fact.

In Fig. 14, A is a receiver which may readily be exhausted by an air-pump communicating with B. From C proceeds a tube dipping into a mercury-basin; and the use of this common device will at once be evident. When the air begins to be rarefied by the action of the pump, and to exert less pressure on all parts inside the receiver, the mercury rises in the tube because of the outside pressure, and the length of the column serves as a measure of the rarefaction within. Thus, 29 in. of mercury will show us that the air in the bell-jar is less dense than when the mercury stands at 28 in.; and, indeed, it is an easy matter to calculate the exact density when the height of this mercury-column and the temperature are given. A bag of oxygen (O) communicates with the interior of the jar by means of D, and the gas can be caused to enter to any desired amount.

A sparrow was placed in the receiver, and the air highly rarefied. Ere long the bird began to exhibit all those symptoms which precede death; but when a little oxygen was turned on, the bird regained its normal state. This experiment, cruel as it may seem, suggested to M. Bert the cure for that great distress which is experienced by aëronauts at high altitudes (p. 105), and he proceeded to put it to the test in the following way. A metal cylinder was constructed of such a size that, whilst he was sitting within at ease, it could readily be exhausted to any required degree. Supplied with a bag of air well charged with oxygen, and accompanied by a sparrow in a cage, he was shut in at thirty-seven minutes past two, and the exhaustive rarefaction at once commenced. He remained for about an hour, and found that the intermittent breathing of air highly charged with oxygen brought the pulse to its normal rate, and removed the nausea which is felt in a highly-rarefied atmosphere.

To resume our study of empty space as produced in the laboratory: If we take still more air out of a tube which exhibits these lovely appearances when the electric spark is passed through, we at length arrive, by con-

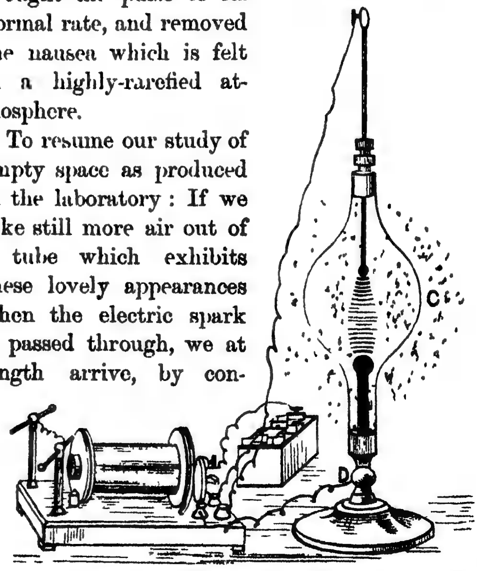

Fig 15.—Passage of an Electric Spark through rarefied Gas.

tinued exhaustion, at a condition of empty space which is incompetent to transmit the spark. It is at this point that another remarkable phenomenon may be observed which has been brought to light

by the labours of one of our great modern physicists—William Crookes.

A little instrument called the radiometer may now be often seen in the windows of opticians, consisting of a globe of glass, within which four vanes are spinning rapidly round (Fig. 16). Nothing is seen to turn them, but they keep on quickly revolving so long as ever sunlight falls on the apparatus. The instrument consists of four arms of very fine glass, supported in the centre by a needle-point which stands in a glass cup, and at the extremities of the arms are fixed thin discs of pith, lamp-blacked on one side. The lamp-blacked surfaces all face one way when in a given position, and the vane apparatus is so delicately balanced as to turn with the slightest impetus. When the globe is well exhausted by a Sprengel's pump, the light of a candle causes the vanes to spin round; but if it be full of air, not even the light of the sun will make them move. There is much about it that puzzles scientific men, but they nearly all agree that the light which falls on the discs slightly heats them, and these in their turn heat the rarefied gas, the resulting commotion among the invisible particles or molecules of air making the vanes move. Even under ordinary circumstances we see many proofs that when air is heated it begins to move. On a summer's day a pathway often becomes very hot, and communicates its heat to the air in contact with it. As a consequence, hot air rises and colder air falls. The visible effect is a quivering motion of objects seen through the currents. At a distance of a few hundred yards we should say that the ground had been seized with a perpetual tremor did we not know that it was perfectly still. An exaggerated form of the same phenomenon may be thus readily produced at any time. Heat a poker to redness, and then hold it in such a posi ion with regard to the lamp that its shadow is cast on the white ceiling; a wavy motion will be perceived on one side of the shadow, which arises from the commotion of air induced by the heated poker.

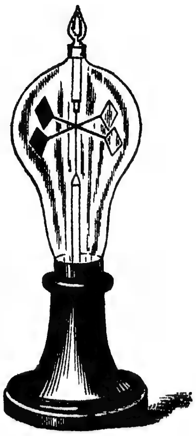

Fig 16.—Crookes' Radiometer.

When light falls on the black surface of a radiometer vane, it is absorbed, and the lamp-blacked surface becomes slightly heated. The motion of the rarefied gas produced is of such a nature as to cause a little more pressure on this black side than on the other. The black side therefore recedes from the candle; the same thing happens to the next vane which comes up, and so the motion is kept on. Crookes found that while black vanes went round one hundred times, white ones only revolved eighteen—a fact which is readily explained. White surfaces absorb or drink in very little light, and thus do not become heated to such an extent as black ones, which absorb nearly all the light that falls on them. The hottest surface produces most aërial motion, and consequently will be most strongly affected; and hence arises the fact of black discs making one hundred revolutions for only eighteen of white discs.

In conclusion:—Our primary object has been the study of empty space; and respecting such approaches to it as are obtainable, we have learnt that this condition is unfavourable to the production of sound or the support of animal life; that a fairly good vacuum transmits an electric spark with wonderfully beautiful results, the same phenomenon appearing on the largest scale in the aurora borealis; that, in a better vacuum still, well-balanced and very light bodies begin to move when the rays from a candle fall on them. But besides these interesting facts we have incidentally learnt many important truths. For example, we have seen that the air we breathe has weight just as certainly as a stone possesses it; that it is this weight of air which presses up water into a pump and mercury into a barometer-tube; and, thinking nothing foreign to our subject which tended to elucidate it, we have besides derived instruction from the scorpion and from the mine, from the octopus, and even from the blood-vessels of one's arm.

# SLEEP.

By Robert Wilson, F.R.P.S.,

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STRANGE as it may seem, scientific men find it extremely difficult to define sleep. It is not exactly a state or mood of mind and body, but a succession of states or moods into which mind and brain gradually drift, and in which the activities of the organs of sensibility and locomotion are tempor-

arily suspended. It is essential to a true definition of sleep that it be further set forth, not only that this suspension of animation is temporary, but that it alternates with the opposite condition of vigorous activity. Life is action; action involves waste, and waste necessitates repair. No living body is capable of sustaining continuous and unbroken activity. The experiment may be tried on a small scale and in a harmless manner. Let any one attempt to wave rapidly a lady's fan to and fro by means of wrist-action alone, and he or she will find it impossible to keep on doing so for any length of time. A period arrives when the wearied hand must stop, because the muscles that act on the wrist-joint require rest to repair the damage or waste caused by the prolonged strain on them.

Perhaps the most curious illustration of this principle is one which Bichat thought belied it. The heart, for example, goes on without stoppage, beating like "a muffled drum" our "funeral march" to the grave. Its action during life never ceases, even in sleep; and it may be asked, How does it repair the waste wrought by its unceasing work? The fact is, the heart does not go on toiling without remission from year's end to year's end. It acts in a state of rhythmical contraction, and every beat it makes is, as we all know, followed by a pause, during which the organ rests and repairs itself. If the time taken up by each one of those little pauses or rests in the course of twenty-four hours be summed, it will be found to amount, strangely enough, to eight hours: a fair enough allowance of sleep for a grown-up man. In a word, the very using of our organs destroys their tissues. Were it not for the periodic recurrence of sleep, which for a time arrests their action and offers an opportunity for renewal, every living body would fret and wear itself away to a shadow. But it is in fact growing whilst it is asleep—in the sense that it is then repairing the destruction caused by the functional activity of the waking hours. During sleep, no matter how deep it may be, the nutritive or reparatory business of the animal frame proceeds without interruption. The heart does not cease to pump its vital supplies of blood into every corner and cranny of the organism. The lungs carry on their function of breathing with scarcely any appreciable difference. The organs which digest the food and convert it into the raw material of flesh, bone, and blood, engage with no diminished vigour in the work of nutrition.

When we have once grasped the idea that what physiologically compels sleep is the necessity for repair, we can without much difficulty understand that this state is under the dominance of periodicity. In other words, the tendency to fall asleep is strongest at regularly-marked periodic intervals of time, which again are conveniently marked by the diurnal revolution of the earth and the alternations of day and night. The silence, the gloom, the hushed darkness of Nature when "wrapped in the sable pall of Night," naturally render it the most convenient season for sleep. Of course in this case, as in many others, Nature revolts against the universal application of a hard-and-fast law. There are many living, moving, flying, and creeping things, to whom night is the natural time for activity. The moth, the owl, the bat, not to mention the carnivorous beasts of prey, are all day-sleepers and night-workers. Attempts have been made to found upon the periodicity of sleep a wide sanitary generalisation. They have tried to substantiate the popular belief that night-sleepers must suffer in health if they become day-sleepers. In the case of the lower animals no conclusive experiments have been made with a view to elucidate this matter. As regards man, on the other hand, the data founded on are usually far from complete. In the class of persons who "turn night into day," either by working or revelling when the rest of the world is reposing, a high death-rate may prevail. But then night-workers are divisible into three classes:—(1) Those who, although they toil soberly at night, persist in working during a great portion of the day also; (2) those who combine night-work with unwise indulgence in the use of stimulants; and (3) those who simply turn night into day with the most prosaic literalness—that is to say, who work at night as they would work during the day, sleep during the day as they would sleep at night, and who do not give way to debilitating personal habits. Clearly it is on this latter class that observation ought to be concentrated. For in regard to the other two the excessive mortality may be traced to other causes than mere night-work—namely, to dissipation, or to foolish curtailment of the natural and necessary period of rest. But where the night-worker does not unduly indulge in intoxicating liquors, where he is careful to sleep during the day as much as day-workers rest during the night, it is impossible in the present state of knowledge to say that he suffers any more from his toil than the generality of men who labour in sunlight. Night-watchmen in the police-force, for example, are not a peculiarly weakly class of individuals.

The degrees of lightness and heaviness of sleep are infinitely varied, and they pass from and into one another in both directions at all portions of the period of repose. Sleep does not always begin with drowsiness and end with torpor. Whilst it lasts it is constantly passing backwards and forwards between these two points—as a succession of states in constant variation—a complex mood of being in which it is not enough to say that the sensory and motor faculties are in a state of suspended animation, but that they are all subjected to different and ever-shifting degrees of inactivity. Bichat brings out this idea of the complexity of sleep excellently in his definition: "Le sommeil général est l'ensemble des sommeils particulièrs." Thus, no general or sweeping dicta can be laid down as to the oncoming of sleep. A man may pass through all the transitions between waking and sleeping in twenty seconds, or three times in a minute. He may even pass apparently with absolutely no appreciable lapse of time between the two extremes. If we are to believe the late ingenious Dr. Macnish—better known as the "Modern Pythagorean," whose weird papers in *Blackwood's Magazine* were the delight of a past generation—sleep, as a rule, comes on gradually. Anybody may verify this by a little personal observation. Unless utterly exhausted, a man may be able to note in his own case how sleep slowly steals over his senses—how there is a strange transition period when the mind is balanced between sleep and waking, and when it is, to use the language of Macnish, "pervaded by a strange confusion which almost amounts to wild delirium; the ideas dissolve their connection with it one by one; and its own essence becomes so vague and diluted, that it melts away in the nothingness of slumber." Concurrently with a loss of sensibility, there is also a gradual loss of voluntary power—as may be illustrated by the slipping away of an object grasped by the hand of a person falling asleep.

Sleep does not merely fluctuate in intensity at different periods of slumber. It varies in amount—or perhaps we ought to say duration—in different individuals. Just before a child is born, its condition in the mother's womb is one of absolutely continuous sleep. If prematurely born, it sleeps on, save when at long intervals it is roused to take a little nourishment. During infancy it sleeps most part of the day away; and then the length of its slumbers goes on diminishing till it reaches a minimum at the culminating-point of fully developed manhood or womanhood. From this point, as the individual "declines into the vale of years," the amount of sleep he requires grows and grows till, when second childhood comes, the veteran, like "Old Parr," sleeps his drowsy life away after the manner of infancy. These facts must be familiar to everybody, and they need no complex apparatus to demonstrate them. But what do they indicate? Surely, a remarkable verification of the idea with which we started—to wit, that the primary office and object of sleep was the renewal of tissue-waste. For we know that in old age the strain of making good broken-down tissue is greatest, because during that period the nutritive forces are most sluggish in action. Then, again, in infancy, although there is comparatively little repair to be done, because waste is minimised, yet growth is swiftly going on. But, practically, growth and repair, for the immediate purpose in hand, are alike. They are both constructive, as opposed to destructive operations. Thus we see that when the pressure put upon the constructive agencies in the human body is greatest, the amount of sleep it takes is at a maximum. When the two sets of forces balance each other, as in a man in the prime of life, the amount of sleep is reduced to a minimum. In his case growth, in the sense of development, has ceased. As for repair, the strain of it bears but lightly on nutritive functions which, in adult life, are in their most perfect and active working order.

What are we to say as to the cause of sleep? It is very easy to catalogue the predisposing causes of sleep, but most difficult to speak with confidence concerning the direct ones. The first and most general predisposing cause of sleep is a negative one. It consists in the absence of everything that stimulates the senses, or oppresses the mind. Darkness or the absence of light, silence or the absence of noise, repose or the absence of muscular exertion, all help to bring on sleep. To some it may seem strange that continuous noise acts like quiet. The truth is that the monotonous repetition of stimuli to the senses produces a level uniformity of impression which is practically, for soporific purposes, equivalent to the absence of impression altogether. In this way the influence of a monotonous chant or lullaby, the "hush-a-bye, baby," of the nursery, the murmur of the waves, the "sough" of wind through the branches of trees, and the dull roar of machinery in predisposing to sleep, may be explained. Sameness of impression also acts in a manner which bears on the operation of another great predisposing cause of sleep—namely, freedom from mental oppressions or activity. It neutralises the self-consciousness of the mind, by making it cease to think of its own

operations. Dr. Carpenter, for example, points out that even when the mind is, by an act of will, directed to the contemplation or evolution of monotonous impressions, the effect is the production of sleepiness. He cites, as an example, a well-known popular remedy amongst scholars for sleeplessness—namely, the automatic repetition of the tenses of a Greek verb. No doubt, if a man is troubled by some exciting anxiety which would keep him awake, owing to the hurrying crowd of disturbing fears that it might engender in his mind, he will probably find it difficult, if not impossible, to bring on sleep. But if by an act of will he can transfer his attention to a dull, monotonous train of harmless ideas—*e.g.*, many sermons and most poems—he will, by a process of self-tranquillisation, place himself under the operation of a predisposing cause of sleep. On this head, however, the late Sir Henry Holland gives one caution. He says, "The influence of the previous state of the mind in procuring or preventing sleep is curious in every way. Minute observation here offers many seeming incongruities which cannot be explained without knowing better than we do its physical causes, and their relations to the sensorial functions. What seems most needful for attaining it, is the disengagement of the mind from any strong emotion, or urgent train of thought. Great anxiety to bring on sleep implies these very conditions, and is therefore more or less preventive of it. The various artifices of thought and memory often fail from this cause. When they succeed, it depends either on the exhaustion becoming more complete, or on the mind being rapidly carried from one object to another; a desultory state of this kind, without emotion, being apparently the condition most favourable to the effect required." It does not appear how carrying the mind rapidly from one thought or object to another can act in any other way than by producing that more complete exhaustion of the brain of which Sir Henry speaks. It cannot produce the uniformity of impression which acts on the drowsy as if it were an absence of impression, and it is very doubtful if the "desultory state" into which the mind is thrown just as sleep is coming on is not the effect rather than the cause of drowsiness.

What are we to say of the *direct* causation of sleep? Although the repair of the exhausted energy of the body, as a whole, is no doubt the general physical cause of sleep, yet there is one specific cause to which we are guided by its prominent symptom. During sleep there is a suspension of conscious mental action. But then, as the brain and great "nerve-centres" may be termed the organs of mental action, during sleep the brain must be in a different condition from that in which it exists at other times. If we seek for the direct cause of sleep in the brain, another circumstance will guide us. We have seen that sleep is not characterised by any fixed unity of state, but that it is a condition of constant and swift fluctuation and change, not only, as Sir Henry Holland remarks, in general intensity, but in regard also to the different degrees of suspension in which particular bodily activities are thrown. From this, one might naturally infer that whatever influence operated on the brain to produce sleep, it must be one which is not constant, but varying, in its pressure. Having come to this conclusion, it is easy to predict that the cause we are seeking for is to be found in the circulation of blood through the brain. It might be expected to supply that rapidly-altering and fluctuating influence which would account for the changing phenomena of sleep. And it must be noted that such a hypothesis, whilst consistent with the complex phenomena of sleep, would not be inconsistent with the wider generalisation that the primary object of sleep is repair, and that its general cause is the necessity the organs of the body labour under of recruiting their exhausted energies. For the brain must be subject to the same fate which enacts waste as the penalty for work done. The putting forth of mental force must be accompanied by the breaking up or wearing away of brain-substance, as may be proved by examining the waste products excreted by a man after many hours' hard study. Such a person throws off by the usual channels more "phosphates," which are the characteristic constituent materials of the brain, than he would do if he were idly amusing himself. Of course, it would be foolish to dogmatise as to the exact manner in which the infinitely minute brain-matter breaks up under the putting forth or "evolution" of force. We may say, however, with Dr. Cappie—who, in his interesting little work on "The Causation of Sleep," has dealt very clearly with this part of the subject—that, after evolution of mental activity, "the cellular elements [of the brain] become so disposed that the active evolution of force is less easy; that they have a less powerful attraction for the oxygen of the arterial blood;" and that these "infinitely subtle vibrations" of the molecules in the brain, which physiologists believe are the physical concomitants of thinking, begin to remit.

Now, it is always noticed that there is a close

relation between the circulation of blood and the molecular nutrition of the tissues. The supply of blood is regulated strictly according to the demand for it existing in the minutest elements of the frame. The heart, it is true, flushes the capillaries of the delicate network which forms the termination of the system of blood-vessels, but only in obedience to the subtle forces of attraction exerted by the molecules of the structure it supplies—forces which in strength vary in direct proportion to the evolution of energy in that structure. The more work that is done, the more demand is there for assimilating nutritive and getting rid of waste matters. Hence the need is all the greater for a plentiful current of blood to bring the one and carry off the other. Applying these principles to the brain, we might without much fear venture to suggest that, either as coincidence or as cause, a diminished circulation in the organ would be found associated with the state of sleep. Experimental research confirms this view.

It would be tedious to explain minutely each step of the investigations that have been made into the condition of the brain-circulation during sleep. Surgeons have sometimes the rare fortune of actually seeing the organ in this condition with the naked eye. The skull is occasionally injured in such a way that it becomes necessary to remove portions of it, and for some time after such an operation a portion of the brain-substance may be seen exposed. Let us say generally on this head that if we could render any portion of the skull transparent we should find sleep visibly affect the brain in this wise: When drowsiness begins to come on, the brain, which is reddish-pink in colour, becomes slowly paler and paler. It also gradually diminishes in volume; both effects being due to the increasing bloodlessness of the organ. When sleep finally sets in, the brain attains its maximum of pallor. Then, suppose the sleeper be roused, what happens? A blood-blush swiftly spreads itself over the brain-surface. The organ regains its former volume. When the process of rousing is carried still further, and the waking state reached, the brain-substance becomes more and more tinged with blood; and as thought and speech are indulged in, the brain becomes redder than ever. Innumerable little vessels, unseen while sleep continued, are everywhere apparent, standing out in bright relief, and the blood is manifestly rushing through them with great rapidity. Then, again, let sleep be reproduced, and the state of matters now described will be reversed—the brain becoming pale and shrunken as before whenever the condition of slumber is reached. Another hypothesis has been disproved—to wit, that as the veins are not seen to be abnormally distended during slumber, it cannot, as was at one time supposed, be their engorgement that produces sleep by unduly pressing on the surface of the brain. We must keep in view that during sleep the brain is not absolutely bloodless. The quantity of blood sent through it is merely lessened, and the rapidity of its current is diminished. When the volume and rapidity of the blood are great, the brain-cells are in the best condition for evolving mental force. When both the volume and rate of the circulation are diminished, as in sleep, these cells have thier activity reduced to the mere level of self-repair. But if we are to find the cause of sleep only in brain-weariness, and the diminished circulation that follows thereon, how can we account for the cases of persons like the late M. Thiers and the First Napoleon, who could command sleep at will? They could make themselves go to sleep, irrespective of brain-exhaustion, at any moment. Now, anything that diminishes the amount of blood sent to the brain, and makes it flow more slowly—even compression of the blood-vessels in the neck that supply the head—will produce sleep. Molecular inactivity in the organ will be thus brought about, as it would be in any other tissue starved of nutrient fluid in the same fashion.

But then, how can the will control the circulation of the blood? The heart is an involuntary muscle—that is to say, its action is not under the control of the will. The little muscular fibre-cells that, like hoops, surround the smallest arteries, belong to the same category. The nervous system within the nervous system—that scattered chain of nerve-centres distributed all over the body, known as the "ganglionic system" of nerves, controls muscles of this type. It therefore regulates the calibre of the blood-vessels, by causing their muscular hoops, to which it sends branches, to dilate or contract, as need may be. Now, there is a ganglionic nervous system in the brain regulating the calibre of its blood-vessels. It is known that in some exceptional cases the will can exercise control over ganglionic centres. They supply the heart, for example, with nerve-fibres; and yet there is a case on record of a gentleman who had power to control at will the action of his heart. He could stop its pulsations whenever he pleased, and might have lived to a good old age had he not been rather vain of his accomplishment. He arrested the action of his heart once too often—his friends finding, to their regret, that neither he

nor they had the power to set it working again. In the same way it may be that men of exceptionally vigorous natures may have the ganglionic nerves of the brain within the iron grip of the will. They may be thus able to turn on or turn off the blood-supply to their brains at will by forcing the ganglionic centres to transmit that nerve-stimulus which causes the arterial coats to contract and stay the flow of the blood-current.

What has now been stated is perhaps the simplest if it is not the newest theory of sleep. Foreign observers have recently attempted to furnish the world with other explanations of the mystery—many doubtfully reasonable, some absurd, but all ingenious—though not sufficiently founded on fact to call for their explanation in these pages.

From what has been said some practical conclusions may be drawn. Whatever tends to quicken the circulation of blood in the brain will prevent sleep. Whatever withdraws blood from the brain will tend to produce sleep. When the drowsy student tries to keep himself awake by wrapping wet towels round his brow, he is striving by chilling the surface of the head to drive the blood inwards. When the sleepless man procures a night's rest, as the result of violent bodily exertion, it is because muscular effort attracts to the muscular system an extra supply of blood, and reduces the quantity coursing through the brain. After a full meal the organs of digestion drain the body of blood to enable them to carry on their work. The brain after a full meal is thus depleted, and sound sleep not only waits upon, but helps digestion. It may be asked, How is sleep produced artificially by the agency of drugs? That is a question on which physicians alone are properly qualified to speak. One may say that any drug that will stimulate the ganglionic nervous system, and cause the blood-vessels to contract, would produce sleep. The ordinary opiates, however, do not act in this manner. The general belief is that they produce a great engorgement of the veins on the surface of the brain, which in turn produces unwonted compression of the organ, and that to this compression may be traced the advent of narcotic slumbers. Besides the facts and phenomena already mentioned in connection with sleep, there are many others into the consideration of which, if space permitted, it might be interesting to go. Let us briefly allude to one of the most important—namely, the duration of sleep—how in some cases a few hours will suffice, and in others a longer period is needed. Dr. Reid, the metaphysician, could work for two days without a break if he got one sound sleep after a full meal. If the stories about Lord Brougham could be believed, he could work on less sleep than most people require. Frederick the Great and John Hunter required only five hours' sleep; but it must not be supposed that because men with exceptionally powerful nervous organisations can dispense with the normal quantity of sleep, it would be safe for everybody to follow their example. The sleep of the heart, which we have seen to amount to eight hours out of the twenty-four, is a fair indication of the quantity of sleep which on an average ought to be allowed to the brain. As Sir Thomas Browne, the learned knight of Norwich, hath it, "Half our days we pass in the shadow of the earth, and the brother of death extracteth a third part of their lives."

## HILLS, DALES, AND VALLEYS: HOW THEY WERE SHAPED AND WORN.

By Professor P. Martin Duncan, F.R.S., F.G.S., etc.

Some years ago travellers saw much more of the scenery of the countries they visited, than we do at the present time. They went by road from place to place, and journeyed over the hills and down the dales, and beheld ever-varying landscapes slowly becoming distinct and then perfect in all their beauty, before they were gradually lost to view. Now we go under most of the beautiful hills in dark tunnels, pass along miles and miles in railway cuttings, and soon lose sight of a charming scene as we rush along in the train. It is only when we are out of the line of railways, that we are on the same pleasurable equality with our ancestors. Still, we can see a greater extent of country more rapidly, easily, and more cheaply than those who could only pass over some fifty or sixty miles a day in a good coach; and all sorts of hills and dales can now be visited during a moderate excursion.

In travelling, we soon observe that the shape and size of the hills and the depth and breadth of the valleys and dales, differ in almost every county of Great Britain, and in every country in the world. And a very little experience in journeying about, proves that certain kinds of shapes and sizes of hills are peculiar to some great districts. Thus, in going from the south-eastern counties to North Wales, many different-looking hills and dales are seen; and, by noticing them carefully, it will be found that they alter in shape, outline, ruggedness, and size, as sets of counties are passed over.

In Kent and Sussex the most important hills are not very high, have bold, rounded slopes in some directions, and are very level at the top in others (Fig. 1). The dales are grassy slopes, with shelving sides, when they are called coombs; or they are sometimes worthy of the name of valleys and gorges, when a river flows through the midst of the hills in a direction across them, as at Guildford, for instance. To [illegible] nences, like Primrose Hill, Highgate, and Harrow, peculiarise the district. Going westward, a strip of country comes in sight where the scenery is much like that of some parts of Kent, and, indeed, some portions of Hertfordshire exactly resemble others in the south-east of England. Journeying on towards the source of the Thames, the hills often look like high flats or table-lands, with deep, narrow valleys in them; and then the Cotswolds show a very long height, traversed by deep valleys and having an abrupt and cliff-like face looking westward. A wide valley—that of the Severn—has to be crossed before the Malvern Hills in Worcestershire and Herefordshire are reached, and it is soon noticed that they are altogether different from any others which have been passed in the trip (Fig. 2). They seem to rise suddenly out of the great plain on the side of the Severn; they are very precipitous in some places, and the top is not level or simply gently rounded. High, as hills, but not quite worthy of the name of mountains, a wonderful view is seen from their highest point. Looking in the direction whence we are supposed to have come, we see the level

Fig. 1.—Chalk Downs near Clanfield, Hants

Cotswolds. It is a perfectly English scene The trees are numberless, the fields are in all sorts of patterns of shape, and every hamlet has its church-spire or tower. We look over a wide valley. If we turn round and look westward towards Wales, a totally different scene presents itself, with striking effect to those who have been always accustomed to the landscapes of the east of England. A sea of abrupt hills presents itself, and the eye follows long, wavy lines of heights, increasing in abruptness and size, until great flat-topped, low mountains close in the remote distance. There is not a plain or a large flat spot to be seen, but ridge and valley, deep dell and rugged top, extend right away to the borders of Wales. But the low hills of the first ridges do not resemble those on which we stand; they are much more uneven, and the country looks very broken; and the distant hills are evidently not like those close at hand, and are higher. We travel across country to Hereford, and make our way into Wales, the hills becoming, at last, mountains with precipices on their sides; deep passes, valleys, and dells penetrate into them, and their summits are bold, often steep and rugged. Nearly every variety of hill and dale may be seen in wandering out of the usual track, from the hop-gardens of Kent to the wilds of Snowdon (Fig. 3); and yet there is an order of coming and going of the different kinds as we travel along. And this remark is true for many a route taken to the right or left of our particular road. A trip on the Continent will enable any one to learn that even great mountains have different shapes, and that parts of the chains which they form present various outlines; some being rounded, others rugged and crossed by deep valleys, and the highest often forming high, sharp peaks, or broad masses. It is this wonderful diversity of shape and height which makes mountain travelling so exciting; and it is the varied nature of the gorges, deep dells, wide and narrow valleys, that adds to the charm of upland scenery.

Most people, in this age of inquiry, like to know the reason why the principal objects in the scenery they visit should differ; and some even speculate concerning the cause of hills, dales, and valleys. Formerly, and indeed not many years ago, it was believed that all these beauties of nature were created as they now appear, and the great naturalist Buffon received a stern reproof from a French academic body, for venturing to state the contrary. There is much to be said for this old-fashioned notion. There are very old trees on many of the hills, which have lived two or three hundred years; there are still older castles, perfect or in ruins, but still standing erect; there are ancient camps on many a height, which were made by the Romans; and there are still older huge stones which were stuck up by more ancient people. Down in the valleys, and on their sides, there are churches and monasteries of some antiquity. All those works of man are on their usual level, and the shape of the ground beneath and around them has not altered. Why should it be said, then, that it ever has altered? Nature is prodigal in variety; no two things are alike, and therefore we cannot expect every hill and valley to be of the same kind. But these facts and ideas require careful investigation, and some very simple observations of nature will lead to the belief, that the variety of the hills and dales, and their different heights and depths, depend upon changes of the surface of the ground and in the earth down to a certain depth, which are still in progress. In going amongst the hilly country of any part of the world during wet weather, the torrents, streams, and little rivers which can be followed up to their sources in the upland dells, are full of swiftly-running water which is not clear and pure, but which is dirty and contains earthy matter. If a tumbler be dipped into the stream as it rushes by, and it be held up to the light, what is commonly called mud is seen in the water, and it is in movement. Soon the water in the glass becomes still, and then the mud which was kept up by its velocity obeys the law of gravitation, by which all things move towards the earth, and settles down on the bottom. When the clear water is poured away, so much mud remains, and so many grains by weight are left behind.

Should we examine this so-called mud, it will not be found to be of the same kind of substance in the south-east of England, near the Malvern Hills, and in the streams about Snowdon. When dried and examined by the chemist, and by any one who is used to work with the microscope, it will be found to be made up of minute particles of minerals. It may consist of tiny grains of sand made of flint, it may be composed of minute bits of chalk, or of these mixed. It may be red, and then the microscope finds curious crystals in it, or flakes of colour, and the chemist detects an oxide of iron something like rust. Again, the mud may be dark, and may contain many kinds of particles, bits of shiny mica, white pieces of stone, portions of slate, and flint sand.

It is quite evident that a great deal of this fine sediment, as it is properly called, passes along a

stream hour after hour, day after day, during wet weather; and it is equally true that the stream carries the same kind of stuff down in one part of the country and different kinds in others. A little watching will show that during a storm of rain in the chalk hills, hardly any water runs down them. It sinks in, but in some places where the country is bare and free from turf, a quantity of chalky water does pour along to the first stream.

Wherever there is a brook, there is some of the chalk being hurried along, and there are flints knocking against each other on the bottom and pounding themselves into round pebbles, the sand from them going off with the rest. It is the mineral substances of these hills, that make up the sediment in the turbulent stream miles away, and running into a great river or the sea. A wet day at Malvern explains where the red mud comes from. There is no chalk and flint there, but hard rock containing many minerals, some of which are shaped with angles and lines and flat surfaces so as to be crystals, and others contain iron. The dense heavy rock is crumbled somehow, and its dust and little pieces are washed down the slopes as red-coloured rills and little streams, and they get at last to the Severn. Up in the deep valleys of Snowdon the rain washes off the peculiar stone of the district. It is not chalk, and it is not Malvern rock, but there is sandstone and slate, and stone made up of crystals. There the quantity of mixed mud that comes pouring along is considerable.

It may be said that this is a very commonplace matter, and so it is; but our fathers saw the same countries in flood-time, our grandfathers did so, and so did the people who lived in England when the Normans came. The old Britons saw the mud rushing along in full stream on their wet days, and so did the earliest of men.

We can trace the sediment to its origin in the hills, and therefore every grain, every pound, and every ton weight of it that has been washed away as mud during all these centuries, was once in its proper place, forming a part of the hill or valley side. It is there no longer, and therefore the hill and valley are smaller by so much.

Suppose that after the sediment has sunk to the bottom of the tumbler, the clear-looking water is examined. Nothing can be seen in it; but if it be poured off and placed in a shallow dish over a gentle heat, the water will be gradually evaporated, and when it has nearly all disappeared, a sediment will appear. This can be dried, weighed, and examined by the chemist, and it really consists of mineral matter which the water had dissolved like so much sugar. A certain number of grains weight can be got out of every gallon of stream-water, and it is found that, as is the case with the muddy sediment, which is visible to the eye in water, this kind of dissolved stuff is more or less peculiar to the country from which the water has come.

Now suppose that a tumbler of water is taken out of a stream when it is clear, will there be any of the dissolved stuff in it? Certainly. In every gallon of perfectly clear river-water there are always many grains weight of mineral dissolved, and that amount came from up the country, from the springs amongst the hills and from the sides of the valleys. It is a very important matter; for although only a few grains came down the river in every gallon of water, there are so many gallons pouring towards the sea year after year, that in the long run the grains will amount to thousands of tons weight. Some years ago it was necessary to calculate the quantity of water that flowed in the river Thames, through Kingston, daily, and it was found that the average quantity in fine and wet weather was 1,250,000,000 gallons in 24 hours. A gallon of the water was examined and found to contain 19 grains weight of mineral, principally carbonate of lime, and this was dissolved naturally in the water, and was of course not to be seen. It is a little sum to do, and if we calculate how many grains weight of dissolved matter 1,250,000,000 gallons will contain, a very surprising amount results. In fact on a fine day, when hardly any mud is being carried down the Thames past Kingston, no less than 3,364,286 lbs. weight of invisible matter is hurrying along to the ocean. This amounts to about 1,502 tons a day, and a ton of carbonate of lime makes up about a cubic yard of solid rock; a cubic yard being a body shaped like one of the backgammon dice and measuring a yard long, high, and across. During each year 548,230 tons stream along. Where does it all come from? for the quantity in a thousand years will be enormous. It comes out of the earth principally, and some from off the surface; and it once occupied so much space, and was solid rock amongst the hills which border the valley of the Thames. The same kind of calculation can be made from every stream, the quantity of the dissolved matter, and its mineral nature, differing according to locality.

It appears then, from what has been now written,

that the hills, dales, and valleys have lost substance, during all the time that streams have been running from them, and rain has been falling on to them. They have changed their shape. But all are not equally deprived, for in some countries the rock is much harder than in others, and it is true that, whilst some hills are much lowered and altered in their shape, and some valleys are deepened and widened, others are very slightly affected. Hence we may conclude that, according to the kind of rock and its enduring power, so are the hills all the higher; and it is a most interesting fact that, according to the kinds of stone and earth of which the hill or mountain is built up, so is its shape. The wear and tear of the outside of the high lands, and the dissolving which is going on within them, produce, according to the yielding or resisting of the different layers and stones, all the varied beauty of the hills, and the flat-topped steep place, the rounded knoll, the rugged terraced heights, and the peaks of the mountains. In the process of destruction, nature produces the beautiful (Fig 4).

There is no doubt that grass, turf, and the presence of what is called soil on the sides of the valleys, and on the hills, saves them from much outside wear. Take away a large surface of grass, and water-channels soon appear. But rain-water soaks in through the grass; and this almost, but not quite, perfectly pure element dissolves minerals as it sinks into the earth, and it comes out sooner or later in springs loaded with matter in solution.

It was stated a page or two back, that the stones on the mountains crumbled somehow, and that the dust was washed away by rain and streams. If this is true, the running water is only the carrier off, and inquiry must be made about the crumblers. The scientific name for these is "agents of denudation." Agent means a power or energy, or a capacity for doing work or mischief; and denudation means uncovering. It is assumed that the surface of the hills and valleys is wearing and crumbling, and that layer after layer is being uncovered, by Nature, as she does work. Let us see what these workers are. They are the heat of the sun, frost, the atmosphere or air, and the waters from the sky, rain and mist. They can act alone, or in company, and they do their work slowly and surely.

Fig 2—The Malvern Hills

When the sun shines fiercely on a summer's day, it crumbles wet earth and clay, and leaves a dust; and it makes hard rocks, like granite, hot to the hand, and they do not get cold again until nightfall. The minerals composing these hard rocks enlarge or expand when they are warmed by the sun; and, as there are different kinds of minerals in many such rocks, some of them have not the gift of enlarging as much as others. Consequently, there is a pulling and dragging going on beneath the surface of the stone, and often a piece cracks or flakes off. Then, as the stone gets cold, some parts of it may contract and get to their original shape more quickly than others, and again there is a chance of breakage. Tough as the rocks may be,

they do yield in the long run, and dusty flakes of mineral are crumbled off, and a fresh surface is uncovered and exposed in turn to the sun. Frost is a terrible crumbler, when the cold is great, stones split, the solid layers of earth fall to pieces, and the wreckage is great on every mountain-side. It acts mainly with the assistance of water. Suppose some rocks, like shale or slate, are on the valley-side, and the last rain of autumn wets them, and leaves the mischief is not found out until the thaw, when the water becomes liquid again, so amongst the rocks splitting goes on; but they remain in their place until the thaw, and then they fall thundering to the bottom of the valley, or else quietly flake off. Whenever there is frost, there is much wear of the rocks.

On going up some mountains, one's feet sink in amongst small pieces of stone and dust, which

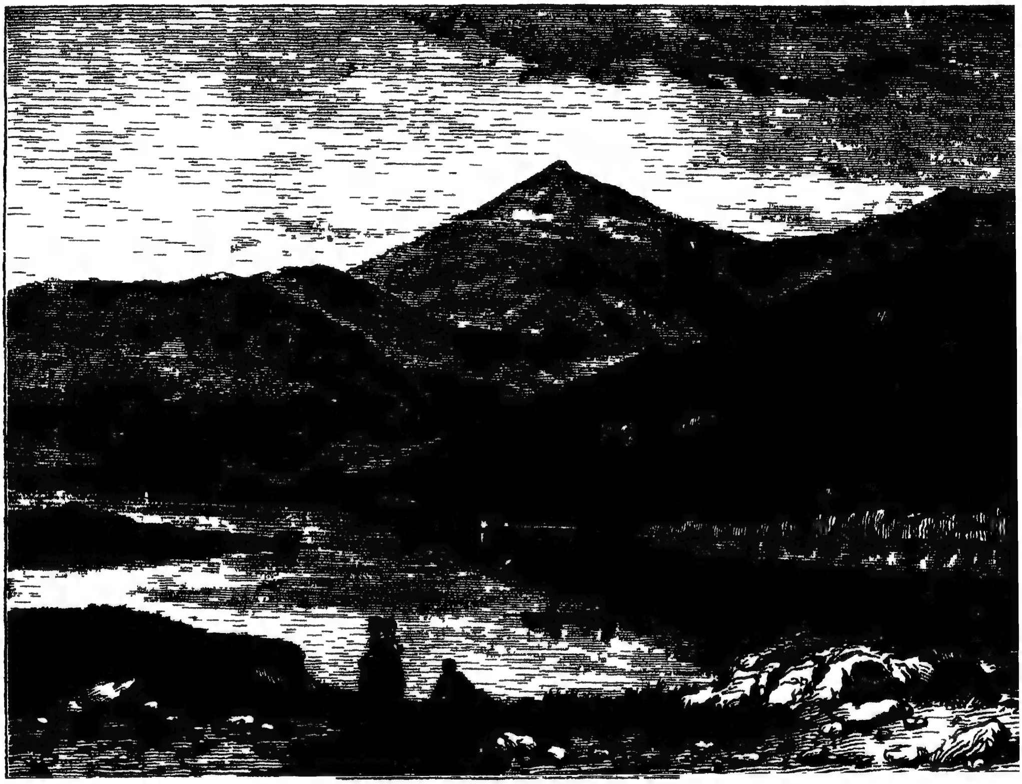

Fig. 3.—Snowdon from Llanberis Lake.

some water between their flaggy surfaces. Cold comes on, and the air feels full of frost: the thermometer falls to 39°, and gradually drops to 32°, and at that point of cold, water becomes solid—or, in common language, it freezes. But if the water only got solid no harm would come to the rocks, as they would have their cracks only filled with solid instead of liquid stuff. Unfortunately for the rocks, the water expands and occupies more space than before as it is cooled down from 39° to 32°; and, as it becomes solid, it occupies much more space than it did when it was liquid water. Just as pipes split when the water freezes, from the enormous power of expansion of its solidifying, and have been wrecked from off the neighbouring hard rocks by the sun and frost.

The air, or atmosphere, does its work of mischief in a mechanical and also in a chemical way. Winds, hurricanes, and gales, as everybody knows, not only remove the dust and the crumbled stuff off the land, but blow down rocks. They add to the force of rain by giving it a greater pelting power, and in the hotter regions of the globe, the furious winds and rains are as destructive as torrents of water. But wind of the gentlest kind does a vast deal of mischief to some mountains and hills, and enlarges their valleys in a remarkable manner, and alters their shape. Where the rain never falls,

and the desert sands can be followed up to the wall-like hills of Eastern Arabia, there the softest gales *sand-scrub the rocks, and do the work of water.* Should the traveller lie down on the sand, with his face uncovered, in the early morning when the day-breeze commences, he finds his skin tingling and his eyes in pain, for the air is full of minute particles of sand. The valleys run right into the bosom of these sandy mountains, and take very sudden twists; their shape is that of a narrow bottom, where never a stream ran, and with wall-like sides receding and terraced at the top. With the wind, the sand comes down the valley, wears the sides, and the terraces give way. Ever scrubbing, the sand wears itself smaller, and the rocks which fall also; and year by year the Wady, as the valley is called, gets broader. There are many specimens of sand-scrubbed statues in the British Museum, for in Egypt, the desert sand does some mischief when it is moved by wind; and on our own sea-coast the sides of many a rock, far out of the reach of the water, is furrowed and worn by this curious method.

Fig. 4.—A Mountain Torrent.

The wind, as it usually blows, acts as an uncoverer or denuder, in that it moves away the dust, the result of sand-scrub and of many other agents. Another, and perhaps the most important, method of acting in wearing hills and rocks, on the part of the atmosphere, is of a chemical nature. The air consists of oxygen gas and nitrogen gas, and they are mixed, and are not in a state of chemical combination; moreover, a small quantity of carbonic-acid gas exists in the air, being made up of a chemical combination of carbon and oxygen. Two of these components of the atmosphere attack many stones, surfaces, and soils, and by changing their chemical condition make dissolvable matter out of the insoluble, or produce a change of softness from hardness, so that crumbling very readily takes place. The oxygen interferes with the minerals which have such metals as iron in them, and the carbonic acid, assisted by the water of mist and rain, dissolves away the limestone rocks, or removes the lime part of the surface of a stone which contains it and sand. The oldest stone buildings, and unfortunately, where the stone has been ill-chosen, many modern edifices, show the results of this action. On some hills and valleys which consist of sandy rock, the atmosphere may not produce much chemical alteration; but many of the fantastic shapes of limestone rocks, and even of the tops of some high mountains, are due to this atmospheric chemistry. It is assisted greatly by the heat of the sun, and by moisture.

The mists, dew, and rain act principally as crumblers, with the assistance of the moving power of the wind, and the altering power of the air. On going up a hill-side, wherever there is a bare face of rock, at its foot there is always some rubbish which has fallen down, and is ready to be swept away by running water or wind. The face of the cliff or rock is rugged and looks weather-worn, and it is said to be "weathered." The carbonic-acid gas,

especially, is dissolved by water, and it thus acts upon a great number of hill-sides, the gas combining with insoluble matters to make them soluble and ready to be washed away.

Two instances will suffice to show the mighty, gradual effect of these agents acting together. Many hills and valley-sides in hot countries, such as in Eastern Hindostan and the Brazils, are covered with a thick layer of bright-red earth, which is so brick-like in colour that it is called *Laterite*, from the Latin for brick. Streams and rain, or water in movement, wash off vast quantities of this sandy, clayey stuff, and the valleys are enlarged and the hills lowered. Underneath this red soil there is a stiffish, whiter-coloured sandy clay; and then, still deeper, lumps of solid rock are found in and amongst it. Deeper still is the solid hard rock forming the foundation of the hill, but its surface is full of holes and is honeycombed, it being made soft at the top and hard a little way down. This rock is either granite, or a rock called gneiss, and they are amongst the hardest and most enduring in some climates. Now, all the clay and the red laterite on the top were once hard granite or gneiss. Rain, pelting as it can only do in the tropics, warm from the heat of the sun and the atmosphere, and charged with the carbonic-acid gas, acts year after year, and century after century; and solid stone, such as we use for kerb-stones and public monuments, is altered chemically, and in its hardness. It is ruined, crumbled, and ready to be carried off.

Fig. 5.—Rhoda's Arch, Wasatch Mountains.

Another instance of slow wear and tear, and which affords proof of the constant taking off or uncovering of the earth on valley-sides, hill-tops, and even on some plains, is interestingly shown in the wonderful country of the western region of the United States. Amongst the Wasatch mountains, where the South River flows into the Rio Grande del Norte, a most extraordinary landscape exists. For miles by the side of the first-mentioned river there is a precipitous high range of rocks; and

sloping from them, a forest region leads to the stream. Dark spruce-fir trees, very high and large, abound; but they are dwarfed by tall pillars of rock, which like pinnacles soar far above them, each being capped by a large piece of stone. There is no exaggeration in saying that there are hundreds of these "monument-stones," and some are 400 feet in length; the majority being between forty and fifty feet. On going to the high range of rocks, narrow and deep valleys are seen to enter it; and they are crowded with an array of these slender erections, which appear as if some intelligent being had formed them and covered each with its cap of stone. But they are not erections; on the contrary, they are the memorial monuments of the once rounded hills, out of which they have been cut, by the crumbling and denudation of the surrounding stone and rock. All else has disappeared. Four hundred feet in height and some square miles in extent of solid rock, has gone, with the exception of these pinnacles. The stone of the country is a kind of "plum-pudding" stone, one in which rounded pebbles are joined together in a hard mass by clay and sandstone; and it is evident that where some of these monuments are just commencing to be made, this stone is harder than elsewhere. The stone is hardest at the surface, and the water of rain and mist, by its falling and chemical powers, after getting into the small cracks, eats its way down a few feet and comes to a softer kind of rock. This is worn by the moving water principally, and soon a little monument is produced, for the solid stone remains as a cap, and keeps the rain off the stone underneath to a certain extent. But the drip soon wears the soft stone below away in long grooves; and in the course of years much of the surrounding earth is carried off, and the pinnacle appears to get higher and higher. Sometimes a dozen of these wonderful remains are in a cluster, and small ones are on the bases of the larger. And in one spot called Rhoda's Arch the beauty of the scene is increased by a natural bridge, a thin rock having been worn through, in the form of an archway, at the same time that the monuments were in progress. The country was once on a level with the top rocks above the arch, and it has all gone, except the monuments and fallen stones. The monument decays at last. It gets thinner and thinner, or its cap is blown off, or worn off, and then it soon becomes a stumpy heap of wearing-away stone (Fig. 5).

The softer the stone forming the hill, the sooner will a valley, which is a natural gutter, be formed, and the wider will it become; and this process of decay depends greatly, so far as its rapidity and intensity are concerned, upon the rain-fall and the heat of the summer and cold of the winter—in fact, upon climate. Water, in moving down into the earth, carries with it some of the carbonic-acid gas, and this dissolves the rocks, and the result comes out in the springs, and is recognised by the chemist in the water of the river, which contains chemicals in solution. And water moving along the ground not only carries off the results of the action of the agents of denudation, but also wears the hills and valleys by its rushing along crowded with moving stone. Water weighs heavily on the bottom and sides of the streams and rivers, when they are deep; and when stone is moving on a torrent-bed, it produces friction. In the long run, the solid rock gives way, and is eroded, and its wreckage is carried with the dissolved chemical matter to the ocean.

The shapes and the outlines of the hills and dales depend then upon their age, peculiar stone, and the intensity and constancy of the action of the sun, frost, the air, and the waters.

The hills, valleys, and dales are still being altered, and there was a time when the valleys were not in existence and the hills were higher.

## THE SOUNDS WE HEAR.

By T. C. Hepworth.

THE faculty which we possess of hearing and appreciating different sounds, is one of our most valued senses. From our earliest childhood we educate ourselves far more by means of this sense than by any other. It is a well-known fact, and one which should teach us how much we owe to our ears, that the deaf and dumb are silent not from any malformation of the organs of speech, but because they lack the sense of hearing. Not only is sound our principal means of intercommunication, but in many other ways it ministers to our wants and to our pleasures. Whether we instance the lowing of cattle, the hum of insects, the song of birds, and the innumerable other pleasant sounds

which add to the enjoyment of rural scenes; or the methodical arrangement of tones which we call "music," and which forms a language which all can understand; we must confess that through our ears we receive much benefit as well as pleasure. It behoves us therefore to learn something of the nature of sound, and of the natural laws upon which it is dependent.

We can none of us fail to be aware that sound takes a certain time to travel from the source of its production to our ears. The distant gun will show its flash and puff of smoke long before its dull boom is made evident to our sense of hearing. The workman's hammer will seem to fall silently upon his work, for the sound does not reach us perhaps until it is uplifted for the next stroke. The thunderclap, although it is really concurrent with the dazzling flash that seems to precede it, often by many seconds, is a still more common illustration of the same phenomenon. But perhaps the most striking instance of this property of sound may be observed when a long file of soldiers is on the march, preceded by a band of music. The men farthest from the band will be quite out of step with those in front, although each man of the company will place his foot to the ground in time with the music *as it reaches his ears.* It is probable that the only men who correctly keep time are the musicians themselves, for they alone can hear the sounds at the exact moment of production.

In 1822 a French commission was appointed to make certain experiments with a view to obtain definite information as to the velocity of sound in air. Two hills, near Paris, were chosen as the theatre of operations, a cannon being placed at each station (Fig. 1). By noting the time which elapsed between the flash of the gun and the arrival of the report, and knowing the distance which the sound had to traverse, these experimenters were able to fix its velocity at 1,118 feet per second, for the temperature which happened to prevail at the time. The mean velocity of sound in air is generally stated as being 1,125 feet per second.

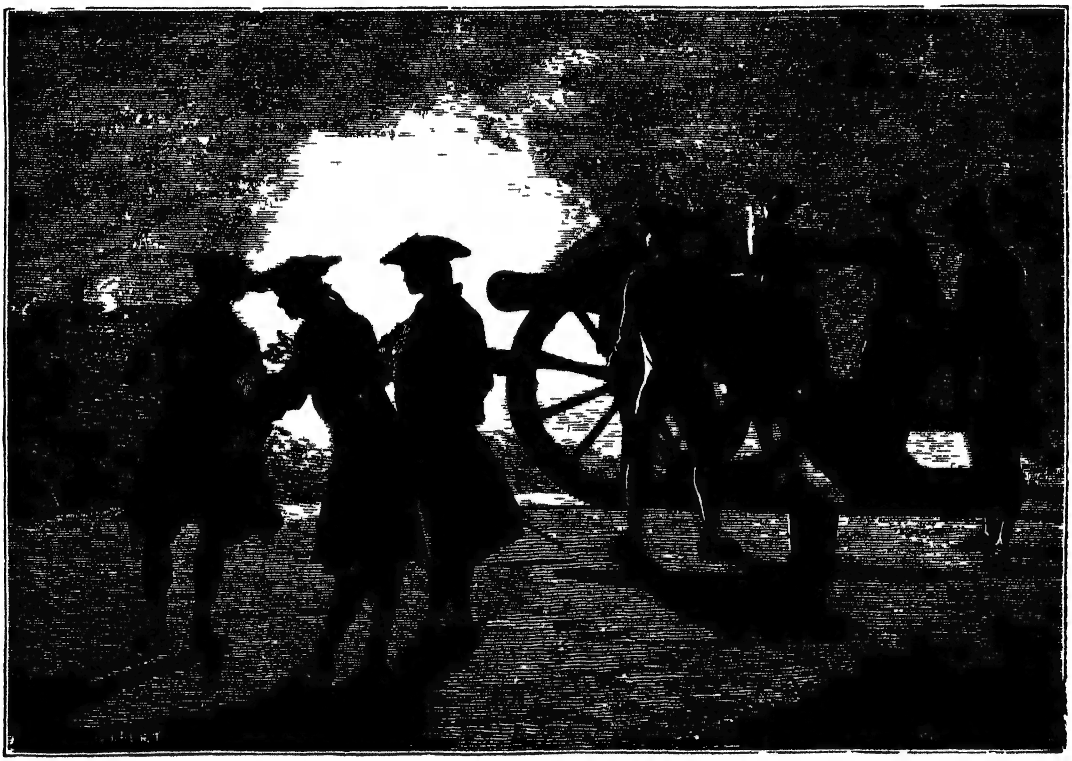

Fig 1.—Experiment to ascertain the Velocity of Sound in Air.

Sound has been defined as "vibration appreciable by the ear." Some bodies are more sonorous than others—that is, by reason of their hardness or elasticity they will more readily vibrate. An

ordinary glass tumbler will, if placed upside down on a table, and struck with the finger-nail, emit but a feeble sound; but if it be held above the table, so that its sides may be free to vibrate, it will give out a clear, bell-like tone. Such vibrations are communicated to the particles of air in the neighbourhood of the sounding body: these give it up to other particles, until in the form of sound-waves they strike upon our ears. These waves of sound have been compared to the ripples caused by a pebble thrown into still water, for they spread in the same manner from the centre of their production. They may be more properly likened to the beautiful undulating waves which appear to pass over a field of standing corn when agitated by the wind. We well know that the several ears of corn do not really travel onward, but they each have a certain limited movement to and fro, which helps forward the progress of the wave. In the same manner the individual particles of air push onward the sound-waves, although their own movement is but of small extent.

The older philosophers were unanimous in supposing that air was the only medium through which sound could travel, and not until the middle of the last century was this theory disputed. But we now know that all bodies, whether solid, liquid, or gaseous, are capable of conveying the appreciation of sound to our ears. It is also certain that the presence of some such body is absolutely necessary for the purpose. This last fact is made evident by an experiment which is an old favourite with lecturers upon acoustics. A bell, having a clockwork or electric attachment for causing it to

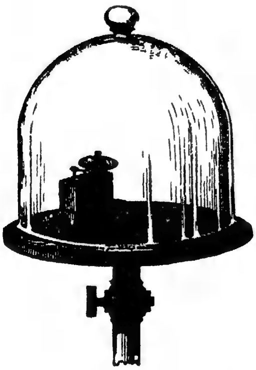

Fig. 2.—Bell under Air-Pump.

ring automatically, is placed under the receiver of an air-pump (Fig. 2). As the air is gradually exhausted the sound becomes fainter and fainter, until at last it ceases altogether; although it can be seen that the hammer is striking the bell as vigorously as ever. As the air is re-admitted the sound is gradually restored. Mountaineers find that it is necessary, when at any great height above the sea-level, to speak with great effort, otherwise their voices are unheard (p. 105). A pistol-shot under the same conditions appears to be little louder than the crack of a whip; the natural rarefaction of the air at such altitudes, placing the operators in the same position as the bell under a partially exhausted air-pump receiver. In order to make this experiment successful, it is necessary to place the bell upon a cushion of wool or some other soft material, otherwise the vibrations would be communicated to the framework of the air-pump, and so to the external air. We learn, therefore, from this experiment, first, that sound in a vacuum is sound no longer; and secondly, that solids are capable of transmitting sound.

There are various atmospheric causes which contribute to obstruct the waves of sound. It is within the experience of everybody that a distant bell is sometimes heard very plainly, and at other times is quite inaudible, according to the direction of the wind. But fog, rain, and snow also interfere with sound-waves, and more or less stop their progress. In clear, cold weather, sounds are much better heard than in summer, when the rising heat from the earth's surface induces currents of air which interfere with their transmission. In the Arctic regions—during the coldest season of the year—it is said to be possible to carry on a conversation with a person at more than a mile distant, the air being there of a uniform temperature and density. For the same reason, sounds which in the day-time would be unnoticed, strike upon the ear at night with startling distinctness. But, of course, the general silence at that time must be taken into consideration.

The velocity of sound in water has also been the subject of patient investigation. Observers were placed in two boats, which were moored at a certain distance apart on the Lake of Geneva. One boat was furnished with an apparatus, by which a submerged bell was struck at the same instant that a charge of gunpowder was ignited in the air above it. In the other boat, an ear-trumpet was used to detect the arrival of the sound through the water, the lapse of time between the noise and the flash being noted by a chronometer (Fig. 3). By this means, it was ascertained that sound travels in water at the rate of 4,708 feet per second, being about four times more quickly than in air. It must

be understood that the velocity of sound in water, as in air, is subject to variation by temperature; the higher the temperature, the greater the velocity.

The travelling powers of sound through solid substances may be stated generally to be far more rapid than through either air or water. The metals, on account of their elasticity, naturally stand at the head of the list. The first trustworthy experiments in this direction were made by the French philosopher Biot, by means of the empty iron water-pipes of Paris. He caused one end of a pipe a mile long to be struck with a hammer. At the other end, he found that two distinct sounds became audible: the first being conveyed to the ear through the metal of which the pipe was composed, and the later sound by the air contained within the pipe. It was thus proved that cast-iron will convey sound at the rate of 16,822 feet per second, or about fifteen times more quickly than air. The phenomenon of the double sound is also heard during blasting operations, provided that the observer is at sufficient distance from the place of explosion. The first sound is conveyed through the substance of the earth, and the other through the air. This conducting power of the earth is said to be taken advantage of by savages, whose practised ears placed in contact with the ground can detect the approach of a horseman long before he is visible.

The transmission of sound through wood can be easily demonstrated by placing the ear at the extremity of a wooden rod, while an assistant gently scratches the other end with a pin. Although the sound may be far too faint to be detected through the intervening air, when heard by means of the

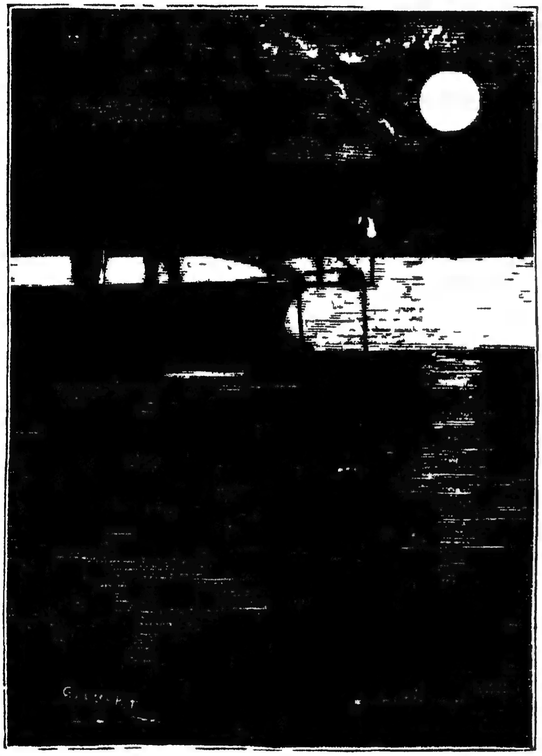

FIG. 3.—EXPERIMENT ON THE LAKE OF GENEVA, TO ASCERTAIN THE VELOCITY OF SOUND IN WATER.

rod it is surprisingly distinct. An experiment, showing the wonderful conducting power of wood, was shown some years ago in London, under the name of the "Telephonic Concert." It took place in a large building, consisting of three different floors. In the basement were placed four performers, who constituted a small orchestra. Attached to the instruments which they played were wooden rods, about half an inch in diameter—one rod for each instrument. These rods passed through the ceiling of the room in which the performers were seated, and through the intermediate apartment to the top floor of the building, where the audience were assembled. In this room the four rods were

connected with the sound-boards of four harps, and the music was most plainly heard by every one present, although it was quite inaudible in the room through which the rods passed. This experiment can also be carried out by means of two pianos similarly connected. We may also produce the same effect upon a small scale by means of a musical box. Let it be placed, wrapped in felt, in any box or cupboard, so that its sound may be completely smothered. If, through a small hole, a rod of wood be connected with it, and the other end of this rod be placed against a box, or violin, the sound will be immediately rendered audible.

It will be observed that the sound in both these cases is helped out by the addition of a sounding-board, or box. And this fact is of extreme importance in showing us how much musical instruments, and stringed instruments in particular, depend for their effectiveness upon the association of some such resounding body. Thus, in the violin, or guitar, we have a hollow box; the strings of a harp are fastened to a similar box; and the wires of a piano are stretched over a board which, looking to the manner in which it is held by the framework, really constitutes the bottom of a shallow box. If we suspend from our finger a violin-string, and attach to it a heavy weight, so as to give it the same tension that it would have when strung on the instrument, we shall find that the sound it will give is merely a dull thrill, very unlike the pure, ringing tone that it possesses when mounted on its proper resonant case. The same effects are observed in the use of the ordinary tuning-fork, which is too familiar to need description. When put into vibration by means of a blow, it is unheard unless held close to the ear. But, if its foot be held against a table-top or any similar body, its note immediately swells out, so that it can be heard at a distance of several yards. These augmented sounds are due not to the strings or tuning-fork, but to the vibrations communicated by them, and taken up by the resonant board or box against which they are placed.

Sounds can also be greatly reinforced by the near presence of resonant cavities. A convenient mode of proving this, is by means of two ordinary glass tumblers. One of the glasses is placed upon a table and is caused to vibrate by a sharp tap from the finger-nail. The other tumbler is then brought near its edge, as shown in Fig. 4, when the sound will at once be almost doubled in intensity. By moving the second tumbler to and fro, the sound is caused to swell out in a curious manner every time the stationary glass is passed over. In nature, the noise of a waterfall is often much increased by the near neighbourhood of a cavern or hollow in the rocks. And we have a still more familiar instance of the same phenomenon in "the murmur of the sea" which children suppose that they hear when holding a hollow shell to their ears. The many unnoticed sounds always present in the air are here augmented by the resonant cavity of the shell.

And now a word about Echoes. According to the old mythological story, Echo was a nymph who had displeased Jupiter by her extreme talkativeness, and more especially by her repetition of certain little matters not altogether creditable to him. She was therefore deprived of speech, but was still allowed to answer any question that might be addressed to her. She afterwards became the victim of unrequited love, "fell into a decline," and was eventually transformed into a stone which retained the same conditional power of speech. Such is the fable in which the ancients wrapped up the ordinary phenomenon which we still call an "echo," but which science explains in a far more prosaic manner.

As an indiarubber ball bounds back from any surface against which it is propelled, so are sound-waves intercepted by any obstructing surface and cast back to the place of their production. This return of the sound-waves constitutes an echo. A certain distance between the source of the sound and the surface which reflects it is necessary for an echo to become perceptible. The reason of this is that the sound requires time to travel from its source and back again; and unless there is sufficient distance for this to happen, the echo is merged into the original sound and is confounded with it—the result being merely a reverberation. In cathedrals and large buildings where the pillars and walls form many obstructing surfaces, the waves reflected from them cause that confused ringing noise observable not only when a person speaks, but also when a chair is moved, or a door slammed. The smallest distance at which an echo of one syllable can be heard is about 140 feet. For sound travels at the rate of 1,125 feet per second. In a fourth part of this time it would go over a space of 280 feet—or 140 feet in one direction and 140 feet back again. Less time than this quarter of a second would not allow for the articulation of even one syllable; but if the distance of the reflecting surface were doubled, two syllables could be uttered; if trebled, three, and so on. Some places are famous for echoes which will repeat themselves again and again. This is owing to the number of different

surfaces which happen to be so placed as to reflect the sound-waves to one common point.

It is very interesting to note that the reflection of sound is subject to the same laws which govern the reflection of both light and heat. Indeed, the concave reflectors shown in Fig. 5 may be used to

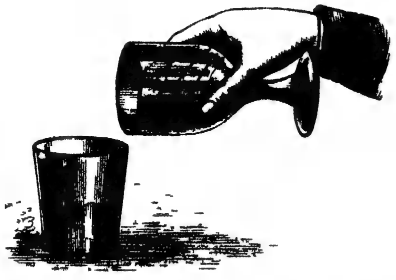

Fig 4 —Experiment showing how Sounds can be augmented by the near presence of resonant Cavities

demonstrate the phenomena connected with either one or the other. We will suppose that the mirrors are placed about thirty feet apart, exactly facing each other. If a bright light be placed at the point marked *a*, which is the focus of the left-hand mirror, its rays will be reflected to the other mirror, and concentrated at the point *a'*. If, instead of the light, a watch be hung at *a*, its ticking will be plainly heard if the ear be placed at *a'* although it will be quite inaudible at any other point. Again, if a brazier of live coals be placed at one focus, a combustible substance at the corresponding point of the other mirror will be ignited. We see here one of numerous examples of the manner in which the forces of nature act in harmony with one another. A sentence whispered to the focus of one reflector is heard at the other, but is inaudible to anybody passing between them. In whispering galleries, such as that in St. Paul's Cathedral, the sound is reflected by the curved wall from point to point, until it reaches the listener's ear.

The speaking-trumpet is an instrument which is dependent for its power both upon the reflections of the speaker's voice from its sides, and the concentration of the sound due to its tubular form. The ear-trumpet used by deaf persons is but a modification of it. A fog-horn, much the same in construction, is used on many parts of our coasts as a warning to mariners, when the weather is too thick for beacons to be visible. This horn is an immense trumpet-shaped tube, furnished, at its mouth, with a metallic reed. An air-pump, worked by steam power, supplies a strong current of wind which sets the reed in vibration. The piercing scream from one of these horns can be heard over the sea for many miles.

The action of speaking-tubes, which are now so common in offices where the employés are separated by different floors, is not difficult to understand. The movement of sound-waves has been already compared to the widening rings which are caused when a pebble is thrown into still water. In the

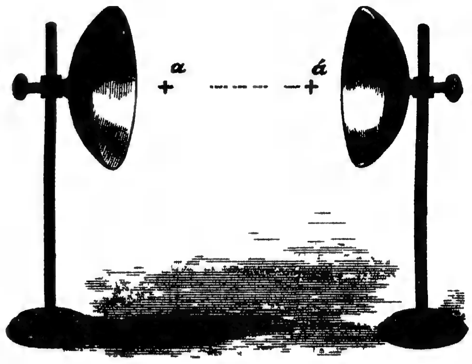


Fig 5 —Concave Reflectors.

speaking-tube these rings, instead of being left to die away into silence, are preserved with all their first intensity until they reach the utmost limit of the tube which confines them.

We will now pass on to the consideration of musical sounds. The line of demarcation which separates mere noise from music is rather difficult to determine. If a door be slammed, the sound reaches our ears as an unpleasant jarring of the nerves which we call "noise." If a bird rises near us, we hear the flutter of its wings as a series of flaps in quick succession, approaching, in some degree, a continuous thrilling sound—but still, it is only noise. In the wing of the bee, and other insects, we have exactly the same vibratory motion, but with a different result, for we here obtain a distinct note, the musical value of which we can appreciate and determine Let us pause for a moment and consider in what this vibration consists. The moving pendulum of a clock will perhaps give us the most homely example of a vibrating body. We find that it oscillates on each side of a place of natural rest, and that the rate or velocity of these oscillations is proportionate to its length. Or, to put it more clearly, we know that if the clock is too slow, we can quicken its movement by slightly raising the weight which is attached to the pendulum, and that if it is too fast,

the contrary action will immediately retard it. By such means we practically shorten or lengthen the pendulum, as the case may be. But, whatever be its length, it oscillates without any apparent sound. Of course, we cannot here consider the "tick," which is caused by the mechanism of the clock. Let us see whether we cannot find means to obtain a sound from this pendulum, or from a piece of metal nearly approaching it in size and substance. The elastic blade of a fencing-foil will answer the purpose as well as anything else that we can hit upon. We will suppose that this blade or rod of steel is about four feet long; that its lower end is fixed firmly in a vice, and that the other end is free. On pulling the free end aside, and suddenly letting it go, the rod is thrown into vibration, and a low fluttering sound is emitted from it, which gradually fades away until the rod is again at rest. We will shorten the rod by placing more of its lower end into the vice; when we now cause it to vibrate, a musical note is the result—but the pitch of the note obtained is very low. By shortening the bar still further, we obtain a higher note; and by adjusting it to different lengths in this manner, we shall find that we can obtain from it every note of the scale.

Now, we have already seen that by reducing the length of a pendulum the rapidity of its oscillations is increased. Exactly the same law holds good in the case of the fixed rod, so that we may guess that the pitch of a musical note is in some way dependent upon the velocity of the vibratory body to which it owes its origin. We just now noticed that a bird's wing will not emit anything but a succession of beats, while the same motion in the wing of a bee will produce a musical hum. Now, the wing of the bird is in fact a counterpart of the vibrating rod as we first placed it in the vice. It merely flutters. But shortened, as in the case of the insect, it is capable, by its quicker vibration, of yielding a musical impression. A musical sound, therefore, requires not only that the vibrations which produce it must be strictly periodic in their occurrence, but that they must follow one another in quick succession. Experiment has shown that the least number of vibrations per second which will give an appreciable musical sound is sixteen; so that we may approximately say that any less number will produce only noise, the pulsations being too disconnected to give anything more than simple percussions. From this lowest sound of sixteen vibrations we can gradually rise by innumerable steps to extremely acute notes which give upwards of 30,000 vibrations per second; but the highest musical sound of any practical value will give in every second of time about 4,000 vibrations.

It would seem almost beyond the bounds of possibility for any substance to execute a movement to and fro four thousand times in the very small period represented by one second. Yet it is not difficult to show that this is an absolute fact, and that it is capable of proof. A series of knocks or taps, provided that they follow one another with sufficient rapidity, will produce a musical note. A card held against a revolving toothed wheel is one mode of demonstrating this. It is evident that if such a wheel be furnished with a counter to record its revolutions (in the same manner in which the turnstiles at public exhibitions are made to check the number of persons passing through them), the sum of such revolutions per second, multiplied by the number of teeth upon the wheel, will give the number of taps or vibrations requisite to produce a note of any definite pitch. If one blade of a vibrating tuning-fork be made to touch a sheet of paper, the consecutive blows thus given to the paper will resolve themselves into a musical note, which of course will be the same note as that given by the fork itself.

Travellers by railway have very often before them an example of the dependence of the pitch of a note upon the rapidity with which the vibrations are transmitted to the ear. When a passing engine is sounding its whistle, the pitch of the note sounded appears to rise considerably at the moment of approach, and sinks below its former pitch directly it has passed. The succession of sound-waves is here artificially quickened, and then retarded, by the rate at which the engine itself is moving to, and afterwards from, the observer. In the same way a vigorous swimmer will, on receding from the shore, meet in a given time the buffet of many more waves of water than he who stands motionless among the breakers.

In many cases the vibrations can be made evident to sight. Thus, the pulsations of a stretched membrane, such as a drum-head, will cause sand placed upon it to jump about. A tambourine treated in the same way will show, by the motion of such particles, the tremor of the air near any sounding body in the neighbourhood of which it may be held. And, in a paper read before the Physical Society, it was clearly stated that sound-waves could be made visible on a delicate film of soap and glycerine, subjected by means of a cardboard support to the influence of a vibrating fork.

Many means have from time to time been suggested of making sound-vibrations self-recording, and Fig. 6 represents one arrangement for obtaining such records. The revolving cylinder shown on the right-

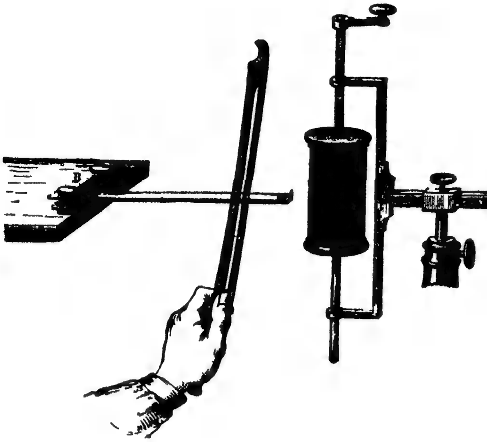

Fig 6 —The Graphic Method of Registering Vibrations

hand side of the drawing is covered with a sheet of paper previously blackened by being held in the smoke of a lamp. A vibratory metal rod (excited by a violin-bow) is furnished with a small point. This point is so adjusted that it will trace a fine wavy line on the cylinder by removing from it the inadhesive lamp-black. Now, it is evident that

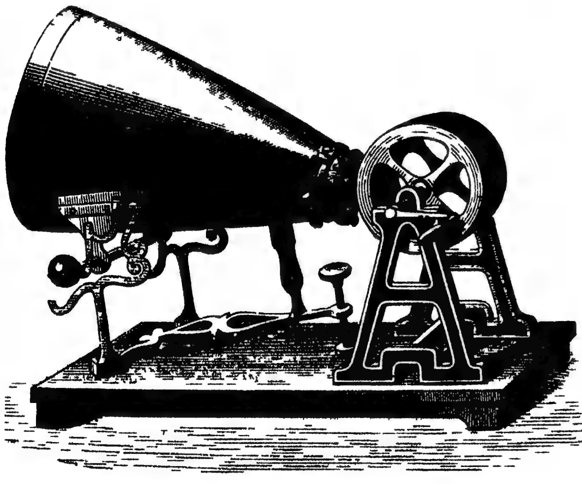

Fig 7 —The Phonautograph.

if this cylinder make one revolution in the space of a second, the number of waves traced upon it will represent the total vibrations per second peculiar to a rod of a certain pitch.

Another instrument which has much in common with the one just described is shown at Fig. 7. It is called the Phonautograph, and it is capable of tracing vibratory curves of any kind of sound, from a clap of thunder to the squeak of a penny whistle. It consists of a barrel-shaped hollow box, made of plaster of Paris or some similar non elastic substance difficult of vibration. One end of this cask is open to the air, for the reception of sound-waves. The other end is closed by a brass ring over which is stretched a thin membrane of bladder or india-rubber. Upon this membrane is fixed by sealing-wax a very light pen or style, the point of which just touches a revolving cylinder, having, like the other instrument (Fig 6), a layer of easily-removed lamp-black upon its surface. The axis of the cylinder is a screw with a coarse thread, so that with every turn the cylinder is moved slightly onward, in order that the style may not go over the same place twice. So long as the style is stationary, the lamp-black removed from the cylinder will show an unbroken spiral line. But when a sound causes the membrane and style to vibrate, an undulating line is produced which varies in character with the nature of the sound. Thus a musical note will give a perfectly even series of undulations, while a mere noise will trace a curve of very irregular figure. It will be interesting to our readers to know that the phonautograph suggested the form of Professor Bell's articulating telephone, about which we have all lately heard so much. A full consideration of the telephone and its doings will form the subject of another paper; the phenomena with which it is connected partaking far more of electricity than sound.

It now remains to say a few words as to the manner in which sounds are made evident to our sense of hearing The external ear has little or nothing to do with the auditory apparatus, and in birds (who may be conjectured to hear as well as mammals) it is altogether wanting. Without entering into the anatomy and physiology of the organ, we may say that the outer passage of the ear is closed by a membrane which measures about one-third of an inch in diameter. This membrane, set in vibration by the sound-waves of the air, communicates its motion to a series of small bones, which in their turn act upon the fluid contents of the internal ear. Within this fluid are spread out the sensitive fibres of the auditory nerve, which conveys to the brain the impression of sound.

Our appreciation of music seems to be in great

measure dependent upon the sympathy with which a vibrating body will act upon another body of equal vibrations. If a sounding tuning fork be held near another of the same note, and its sound be suddenly quenched, the second fork will sound vigorously, although it has not been touched, except by the trembling air. Two fiddle-strings tuned to the same note will in like manner act upon one another. Now, in the internal ear we have a wonderfully delicate organ which follows the same law. It consists of a number of fibres—indeed, we might describe it as a harp having thousands of strings. It is supposed that each of these strings is sensitive to a certain musical pitch; so that when we are listening to orchestral music, each chord that we hear as a compound whole is unravelled, as it were, by our ears into its constituent tones, each tone there seeking out its counterpart, and urging it into sympathetic vibration.

It must be understood that we have in this paper taken a necessarily brief and very general view of the subject of sound. The different headings which it embraces are so extensive in their bearing, and so intricate in their investigation, that they might each form matter for many pages. By taking this general view of acoustical science, we have at least paved the way for the future more detailed consideration of various phenomena connected with the sounds we hear.

# PETRIFACTIONS AND THEIR TEACHINGS.

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MOST people have some general ideas as to what scientific men mean when they speak of "fossils" or "petrifactions," but the notions attached to these terms are not always very clear and precise, and considerable uncertainty prevails as to the mode in which these bodies are found, the methods which are employed in studying them, and the principal deductions which may fairly be drawn from their nature in different cases. In the following article, therefore, we propose to briefly consider the points above alluded to, and to deal shortly with the questions as to where fossils are found, what they are, how they are studied by scientific observers, and what are the more important lessons which they teach us.

As to the first question—namely, Where do we find fossils?—it is sufficient to say that all the objects which we call by this name are found buried in the earth. The name "fossil" itself is in allusion to this fact (from the Latin *fossus*, dug up). All fossils, then, are found in the earth, some simply buried in the comparatively soft sands, clays, and gravels which cover such large portions of the dry land, while others occur locked up in the stony embrace of the hard and compact rocks, which form the solid framework of the earth's crust, and from which they can only be exhumed by the use of the hammer and the chisel.

In the next place, What are the objects to which we apply the term of "fossils"? In all cases, when we come to examine into the matter, we find that fossils are the remains of animals or plants which formerly lived upon the globe, and which have been buried in the earth by natural causes; or they consist of objects from which we can certainly infer the former existence of such animals or plants. Most commonly we have in fossils actual portions of one of these buried animals and plants—a shell, or a bone, a stem, a leaf, or the like—and for this reason the name of "petrifaction" is not a good substitute for that of "fossil," since the former implies that the object so called has been really "turned into stone." This is not by any means necessarily the case. On the contrary, fossils are often little, if at all, changed from the original constitution which they possessed as parts of some once living animal or plant; and even when they look quite stony, this is generally only due to the fact that all the interstices and cavities of the original body have been filled with earthy or mineral matter derived from the surrounding rock. When we find in the earth an actual bone or shell, or a piece of wood, or a leaf, we can, of course, at once assert positively that there once existed actual animals or plants to which these belonged; though it may not be out of place just to notice that people did not always reason in this way. At one time it was thought that the objects which we call "fossils," however closely they resembled parts of actually living animals and plants, had really nothing to do with the former existence of living beings, but that they had been formed in the rock, by what one

might call a kind of fermentation, in virtue of which the particles of the rock arranged themselves so as to give rise to bodies resembling shells, bones, and other organic forms. It is hardly necessary to say that no one nowadays would credit the inert particles of any rock-mass with any such inexplicable formative power. We have, however, to remember that fossils are not necessarily actual parts of animals or plants which were once in existence upon the earth, though this is very commonly their nature. Any object or any marking in the rocks, from which we are enabled to judge of the former existence of an animal or a plant, is properly called a fossil. Thus, an animal walking across the wet sand of the sea-shore, or over the soft mud of an estuary, leaves a series of *foot-prints*, from which we can not only infer the former existence of the animal itself, but from which we can often actually judge as to the character and structure of the animal which made the prints, though we may never have seen its bones. Such foot-prints, then (Fig. 1), though they have never themselves formed parts of the body of any animal, are still rightly called "fossils." Similarly, a plant buried in the soft mud or sand at the bottom of the sea or of a lake, may itself decay and disappear, but may, at the same time, leave an indelible impression of its stem or its leaves upon the soft material in which it is imbedded. Should this sand or mud become hardened into rock, this impression may be so perfectly preserved that we can tell accurately the kind of plant by which it was produced; and this, too, we should with propriety call a "fossil." Again, if we imagine such an object as the shell of a periwinkle or a cockle to be buried in the mud of the sea-bottom, it is clear that the soft surrounding material would fill the whole or the greater part of the interior of the shell; and if we further imagine the mud to be slowly hardened into rock, it is clear that we should find in the inside of the shell a sort of stony kernel, which would faithfully represent the shape and markings of the cavity in the interior. If we broke open the rock, we should either find the actual shell, with this kernel or "cast" in its inside; or the shell might actually have been dissolved away, and might have disappeared, leaving for our inspection the *cast* alone (Fig. 2). In such a case, we should still call the "cast" a "fossil," and though it had never itself formed part of any animal, we might still be able to tell with certainty the kind of shell within which it had been formed.

Fig 1 A Slab of Stone, with Ripple-Marking, and showing the Foot-Prints of an ancient Newt-like Animal, from the Coal-Measures of North America. (One-eighth of the natural Size.)

We have, in the next place, to consider the methods in which fossils are studied by scientific observers; and in this connection the first point to notice is that the modes of study available in dealing with living animals are only partially applicable to the science of fossils, or *Palæontology*, as it is technically called (from the Greek *palaios*, ancient; *onta*, beings; *logos*, discourse). In studying living beings, the naturalist has the immense advantage

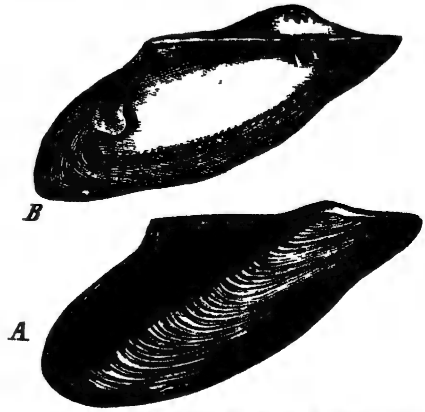

Fig. 2 —(A) Shell of a Fossil Bivalve Shell (*Gervillia*), viewed from one Side (B) "Cast" of the Interior of the same, the actual Shell having disappeared.

of being able to examine all the parts of the animal, whether these be soft or hard. Not only can he investigate the form and structure of any skeleton which the animal may possess, but the muscles, nerves, internal organs, and soft tissues generally are open to his inspection. Hence naturalists usually decide upon the characters and position of any given animal according to the peculiarities presented by its soft parts, and they attach comparatively little importance to the nature of any hard structures, such as shells or bones, which may be present. The student of fossils, however, is in a totally different position. When animals or plants are buried in the earth, all their soft parts decay and disappear. Almost the only exceptions to this —and they are exceptions which prove the rule—are cases in which animals have been preserved in the frozen ground of the far North, as in an ice-house. Thus the bodies of individuals of the Northern Elephant or Mammoth, now extinct, have been found in the frozen soil of Siberia, with their flesh and hair still attached to them, and, indeed, little altered since the death of the animal. Cases such as these are, however, of the most exceptional character, and the same may be said of the few remaining instances in which the soft parts of animals are known to have been preserved in a fossil condition. Two things follow from this. In the first place, we can never expect to find in the rocks any remains of animals which are entirely soft, and which do not possess any hard structures or skeleton at all. Hence, a vast number of animals, such as earthworms, leeches, sea-anemones, jelly-fishes, sea-slugs, and many others, are either unknown as fossils, or are only recognisable by means of markings which their soft bodies may have left after their death upon the mud of the sea-bottom, or the sand of the sea-shore. At the same time, we are not justified, because we do not find these and similar animals as fossils, in concluding that they did not *exist* in past time—the probabilities of the case being all the other way. In the second place, as regards those animals which *are* found in the fossil state, with wholly insignificant exceptions, the student is unable to investigate anything but the hard parts or skeleton, since all the soft parts have disappeared in the process of fossilisation. Hence, the student of fossils has to proceed in his work by methods less perfect than those open to the naturalist. The latter decides upon the nature and position of any given animal, as we have seen, mainly from the anatomical characters of the muscles, nerves, internal organs, and soft parts generally; but the former has to arrive at a similar decision without any other materials on which to found a judgment save such as may be afforded by the hard parts or skeleton, which can alone be preserved in the rocks.

Nor does the above adequately express the difficulties against which the worker with fossils has to contend. Not only has he nothing more than the skeleton of the animal to go by, but very often he does not even get that skeleton in a perfect condition. It is true, of course, that we often meet with the skeletons of small animals, such as the shells of shell-fish and the like, in an unmutilated state. Even in these cases, however, the fact that the shell has been buried in the rock, and is filled with mineral matter, often prevents our studying it fully, since we can examine, perhaps, only its exterior surface, or we may be able to see only a part of it; so that its most important characters may be lost to us. In the case of the skeletons of the larger animals, on the other hand, it is rare indeed to meet with perfect specimens in a fossil condition. The visitor to the splendid geological galleries of the British Museum is apt to form a somewhat different opinion; but the above is the real truth. Generally, the student of fossils has little more presented for his inspection than a few detached scales, a portion of a skeleton, a number of bones dislocated from their natural positions and confusedly jumbled together, or, it may be, a single bone or tooth. Even when he may possess a very large series of bones, there is the strongest probability that these were found in the rock altogether disconnected and detached from one another; and even if they should belong to the same *kind* of animal, they will probably belong to many *individuals* of the same, so that there still remains the task of piecing together these scattered and fragmentary remnants, and of showing whether or not they have any real connection with one another.

In accordance, then, with what principles and laws can the student work out the problem we have just indicated—a problem which at first sight might appear to be one beyond human powers? The answer to this question is to be found in the fact that the various parts which compose any living body, whether animal or vegetable, invariably bear a certain relation to one another, and are mutually inter-connected in some definite and for the most part discoverable manner. Each organ and each structure in a given animal stands in some relation to all the other parts and organs of the same animal, the peculiarities of the one corresponding with definite peculiarities in

all the others. The *law* of this relationship—its why and wherefore—we do not know, but the fact remains as a piece of empirical knowledge, which we can use without knowing its fundamental import. It follows from this that certain structures and certain organs are always found together, and are never found apart. The one *implies* the other; and, if we know that the one structure is present, we can assert with an approach to certainty that the other was present also. We have to make the reservation that this association of different structures with one another is known to us only as a matter of experience, and that, in our ignorance of its real reason, we are not justified in asserting positively that it has invariably held good throughout past time. Possibly, we may—indeed, we sometimes do—find structures which are generally associated with other particular structures, to be occasionally accompanied by organs of quite a different nature. Still, our experience is now a wide one, and it is upon this empirical law of the general or constant association of different organs and structures with one another that the reasoning of the student of fossils must be based. He has only a small portion of each animal open to his examination, and from the characters of this he must *infer* what were the characters of the parts which he cannot examine directly. If our knowledge were sufficiently complete; if we could satisfactorily explain such apparent departures from this law as we already know; and, still more, if we had any real knowledge of *why* certain structures are associated with each other: then we should doubtless be able to reconstruct a now lost and extinct animal from a mere fragment of its skeleton, and to demonstrate with certainty what *must* have been the form of the missing parts. As it is, though allowances must be made for the imperfection of our knowledge, it is wonderful with what precision the skilled worker in this field of science can reason from what we know to what we do not know, and can build up and restore an entire animal from detached fragments of its bony framework.

The working of this law of the "correlation of organs," as it is technically called, will be readily understood if we select one or two examples of its practical application. Suppose, for instance, that we had dug out of the earth such a fragment of a fossil bone as we have represented in Fig. 3; how should we proceed to determine the structure and relationships of the animal to which it belonged? In the first place, then, our knowledge of the anatomical structure of living animals—without which it would be utterly futile to attempt to solve even the simplest problem of this nature—would at once tell us that the bone in question is the broken half of the lower jaw of a quadruped or "mammal." This, of itself, would convey a good deal of information, for we should be at once able to infer with certainty that the animal which originally owned this bone was one which suckled its young, that its skin was more or less extensively covered with hair, that it had at least two legs, and probably four; that its skull was jointed on to its back-bone by a double joint; that it breathed air directly; and that it had hot blood. All known living animals which have a lower jaw at all like the one here under consideration, also possess the other peculiarities just mentioned; and we are justified in assuming, in the absence of direct proof to the contrary, that the same was the case with animals which formerly inhabited the earth, but which have now disappeared.

Fig 3.—One Half of the Lower Jaw of the Cave-Lion (*Felis spelæa*), partially broken From one of the Caves of the Mendip Hills. Reduced in Size. (*After Boyd Dawkins and Sandford*)

We should, in the next place, notice that this broken half of the lower jaw still contains, firmly inserted in their sockets, one of the front teeth,

an eye-tooth, and three of the back teeth. We should further observe that all those parts of these teeth which are visible above the bony substance of the investing jaw, save the limited portion once covered by the gum, are invested by a continuous layer of bright, shining enamel. Lastly, we should find that the eye-tooth is remarkable for its great size, and its pointed and conical shape, and that the back teeth are equally remarkable for possessing pointed crowns, with sharp-edged and scissor-like edges. Now, the next step in the investigation at present before us, is to compare this lower jaw with the same portion of the skeletons of known living quadrupeds; and this comparison is rendered easier because we know that no animals, save such as are "carnivorous," or live upon the flesh of other animals, possess similar large and pointed eye-teeth, and similar serrated and sharp-edged back teeth. It is obvious that this form of the teeth is an adaptation to the habit of killing animal prey for food, the pointed eye-teeth being used to kill the prey, and the sharp-edged back teeth being employed in cutting up the flesh into morsels sufficiently small to be swallowed. Acting upon these considerations, we should at once seek to compare our fossil jaw with the jaws of the ordinary "beasts of prey" (*Carnivora*), such as dogs, bears, wolves, cats, tigers, lions, and the like; and we should find that the unknown bone which we had exhumed is clearly part of the skeleton of an animal of this class. No other living quadrupeds possess teeth similar in their character to those of the fossil now in question. This conclusion, however, carries with it a number of inferences of more or less importance. We know from this that the possessor of this jaw lived upon animal food; that its lower jaw was so jointed to the skull as to allow principally of backward and forward movements; that it had four well-developed legs, and that its toes were terminated by sharp and crooked claws.

Fig 4.—Skull of the living Lion (*Felis leo*), reduced in Size

Pursuing our researches in greater detail still, we should next compare our fossil jaw with the jaws of various kinds of living beasts of prey, and we should discover that we are dealing with a jaw hardly, if at all, distinguishable from that of the living lion. We have figured here the complete skull of the living lion, and it will at once be seen what portion of the lower jaw is preserved in the fossil, and how close is the likeness between the living and the fossil form. Our jaw, in fact, belongs to the great lion, which once lived in England, as well as in most parts of Europe, and which is known as the "cave-lion." This final conclusion enables us to infer still more minute particulars as to the structure and mode of life of the animal which owned this jaw. We are now able to assert with certainty that its claws could be retracted within sheaths of the skin by the action of elastic ligaments; that it walked upon the tips of its toes; that its tongue was roughened by little horny prickles, which enabled it to readily scrape off the flesh from the bones of its prey; and that the pupils of its eyes assumed the form of a vertical slit during the day-time.

Even, therefore, if we had never found any other bones of the cave-lion than the lower jaw here figured, we should still be able to decide as to the kind of animal which originally possessed this jaw, and we should even be able to reconstruct the entire skeleton for ourselves. Of course, it is not

in every case that the problem set before the palæontologist is as easy a one as this. The fossil may be much less perfect, or rather much more imperfect, than the jaw which we have selected; and the type to which it belongs may be a much less marked, and a much less easily recognisable one. Moreover, some fossils show an association of characters which are now only found apart, so that we should not always be able to reason with absolute certainty, from the known recent forms, as to the structure and habits of the fossil animal. Still, the instance we have chosen is a good one, as illustrating the *method* in which palæontologists carry on their work, this method in all cases consisting in a comparison of the imperfect fossil specimens with the comparatively perfect specimens of living animals of the same or of related types. Nor does it matter what may be the nature of the fossil; the method of procedure is the same. If we have to do with a piece of the skeleton of a fossil sponge, a coral, a sea-urchin, a crab, a limpet, a cockle, a cuttle-fish, a fish, a reptile, or a bird, we should proceed in just the same way. We should first use our knowledge of living forms to enable us to decide broadly to which of the great divisions of the animal kingdom the fossil under examination belonged, and then, in the next place, we should compare it with the skeleton of its nearest existing relations, gradually narrowing the circle of possible affinities, and trying, if possible, to place it in or near some group with which it could be directly compared.

As our aim here has simply been to illustrate a general principle, one example is as good as a score, and we shall, therefore, merely content ourselves, in conclusion, with pointing out some of the most important bearings of the science of fossils, as thus elucidated, upon various other departments of human knowledge. In the first place, we find that while we cannot study fossils except by first acquainting ourselves with the structure and characters of living beings, our knowledge of the former has in turn vastly helped us in our investigation of the animals and plants now in existence upon the globe. Many cases, for example, are known, in which living animals are separated from one another by wide gaps, and in which we can place a long row of fossil forms to fill up the apparent interval. Again, there are many points connected with the present distribution of animals and plants upon the globe, which are intelligible only when we come to study the distribution and range of allied forms in past time. In another respect, fossils afford us most important information as to the way in which the rocks forming the crust of the earth have been originally formed. Thus, if we find any bed of rock to be filled with the remains of corals, sea-urchins, or other animals which we know at present as inhabiting salt water only, then we can infer with certainty that this rock, even though it may now be situated at the summit of our highest mountains, must have been formed originally at the bottom of the sea. In the same way, if the rock should contain the skeletons of such shell-fish as we know now to inhabit rivers or lakes, then we are justified in concluding that it was formed in fresh water. If we meet with the bones of land-animals mixed up with marine shells, then we may suppose that the rock was originally deposited as a bed of sand or mud in the sea, but in the immediate neighbourhood of a coast-line, or at some point where a river debouched into the ocean. If the rock, on the other hand, be charged with the remains of terrestrial plants, we infer that it was either itself an ancient soil, or that it was formed in the sea or in a lake in close vicinity to the land. Finally, the study of fossils leads us to very important conclusions as to the distribution of dry land and sea in past periods, and as to the climate of different parts of the earth's surface during successive epochs. Should we meet with the trunks or leaves of palms, or the remains of ancient coral-reefs, we are warranted in supposing that we have here clear indications of a climate of almost tropical warmth. On the contrary, if we find the bones of the reindeer or the musk-ox, we are equally entitled to regard these as signs of a cold or nearly Arctic climate. In this manner, and in many other ways, the student of fossils finds himself called upon to consider, and in many cases to decide upon, a vast number of problems relating to the former history of the earth, the climatic vicissitudes which it has undergone, the changes which have taken place in the disposition of the dry land and sea, and the nature and mode of life of the successive races of animals and plants which have peopled the surface of our planet. In a word, the science of palæontology constitutes one of the most important of the elements of the general history of the earth, since the time when first it became the theatre of life.

# MILK.

By Professor F. R. Eaton Lowe,
*Author of "The Chemistry of the Breakfast-Table."*

MILK is the only fluid which naturally contains all the constituents of the human body. It forms the sole sustenance of the young of all animals which suckle their young; and from it alone the muscles, bones, blood, hair, nails, and internal organs, are derived. All these various forms of organic matter are, by some process which science at present is incompetent to explain, derived immediately from the blood, which may accordingly be regarded in the light of liquid flesh.

This liquid flesh, rich in all the materials requisite to form the solid and fluid parts of the body, is kept up in infancy solely from the milk furnished by Nature for the purpose of nutrition. From whatever source the milk is obtained, it is found to be composed of the same ingredients, although the proportion of these constituents slightly varies. Thus, milk from one animal is richer in sugar; that from another has a larger proportion of water; while that of a third species has a smaller percentage of inorganic salts. A glance at the constitution of this all-sustaining and all-sufficient food will serve to indicate the principle which should guide children of larger growth in the selection of their diet. Before proceeding to an analysis of milk, it will be profitable to trace the action of certain kinds of aliment upon the human system. Physiologists have ascertained that in order to build up the muscles, or what is usually termed flesh, we must make use of food containing in some form the gas called nitrogen. Such an aliment is found in the fibrin of lean meat, the gluten of wheat, or the albumen or white of an egg. To keep up the heat of the body (a temperature amounting to nearly 100° Fahr.), we require a different kind of food—one containing a large proportion of fatty or oleaginous matter. This we may readily obtain from the fat of animals, so that in a meat diet we have both kinds of food presented together.

The reader will now understand the distinction between "flesh-formers" and "heat-givers," or the *nitrogenous* and *oleaginous* classes of food.

It must not be supposed that animal food alone will furnish us with the necessary admixture of flesh-forming and heat-giving materials.

A purely vegetable diet is capable of affording all that is required in the shape of aliment, although in a less concentrated form. Thus, the gluten of wheat and other grains corresponds to the fibrin of meat; while the sugar and starch contained in the grain are converted into fat by the action of certain fluids secreted during the process of digestion. The ox, elephant, hippopotamus, and other great quadrupeds, are herbivorous, or graminivorous; their massive muscles are derived from the use of food selected solely from the vegetable world. While amongst mankind vegetarianism has been found not incompatible with the highest mental and physical development.

Now, let us examine the composition of milk, and endeavour to ascertain whether it contains those nitrogenous and oleaginous elements which we have seen must form the predominant principles in every food calculated to promote the growth of the body. We all know that when milk is left undisturbed for some time, an oily fluid, called cream, rises to the surface. This it does by virtue of its lightness, or, in other words, its "low specific gravity," compared with that of the water which forms the bulk of the liquid. This cream is simply oil or butter, and is the oleaginous principle of the milk, corresponding to the fat of animals. When examined by the microscope (Fig. 1), the cream is found to consist of a multitude of little globules, perfectly spherical, inclosing the oil in a thin pellicle or membrane.

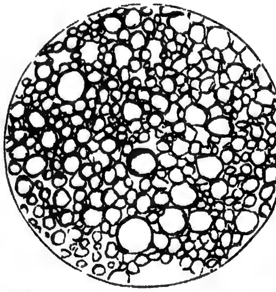

Fig. 1.—A Drop of Cream, as seen under the Microscope. (Magnified about 200 Diameters.)

In the process of churning, this membrane becomes ruptured, and the oil or butter thus set free unites into a mass, more or less solid according to the temperature. The opacity of milk is produced by the suspension of these microscopic oil-bags in the clear liquor; and when complete separation has taken place, the opacity becomes less dense, and a bluish tinge is produced. The more numerous the oil-globules are in a given quantity of milk, the deeper is the opacity, so that, in general, the eye will serve to distinguish good milk from bad.

Having removed the oleaginous principle, where are we to look for the flesh-forming or purely nourishing element? The process of cheese-making will serve to enlighten us on this part of the subject.

From the clear liquid, a solid, called curd, is separated by means of rennet, or, as in Holland, by muriatic acid. This curd, dried, salted, and pressed, constitutes cheese, which the chemist calls *casein.* Casein resembles in composition the fibrin of meat, and is therefore that element of the milk from which the muscles and muscular organs of the young animal derive their substance. A rich cheese contains some oleaginous matter derived from the cream purposely left in the milk; so that in this substance we have a valuable article of diet, comprising an admixture of both kinds of alimentary matter. In addition, however, to fat and casein, the body requires for its complete sustenance other substances, called salts, because they crystallise like common table-salt. For instance, the bones contain phosphate of lime, and salts of potash and soda are always present in the blood. If we make use of food deficient in lime, the solidity of the bones will necessarily be interfered with.

It is from this cause that the disease known as *rickets* is produced in children. Again, salts of iron must be present in the blood, to produce a healthy and vigorous constitution, and, in fact, the red colour of that fluid is, to some extent, due to the presence of iron. Tincture of iron, or steel wine, as it is often called, is administered to persons whose pallid complexions indicate a deficiency of that metal in the blood.

Milk, then, would not serve for the sole sustenance of infancy, if these salts were wanting in its composition. Accordingly, if we evaporate a portion of the clear whey which remains after the formation of curd, we shall be able to obtain these salts in crystals. Crystals of sugar will also be obtained. To this chemists have given the name of *Lactose* or sugar of milk. It differs somewhat from cane-sugar or *Sucrose,* as it is much less sweet, and feels harsh and gritty to the teeth. A large quantity is exported from Switzerland, where it is prepared from the whey produced in the manufacture of the famous Gruyère cheese.

The reader will now be able to understand the following table by Regnault, which represents an analysis of milk from three different sources:—

| | Cow. | Ass. | Woman. |
|---|---|---|---|
| Water ... ... ... ... ... ... | 87·4 | 90·5 | 88·6 |
| Oil or Butter ... ... ... ... | 4 | 1·4 | 2·6 |
| Lactose and soluble Salts ... | 5 | 6·4 | 4·9 |
| Casein, Albumen, and fixed Salts ... ... ... ... ... | 3·6 | 1·7 | 3·9 |

An examination of this table will show us that there is considerable difference in the proportion in which the constituents occur in the three kinds of milk analysed by Regnault. That furnished by the human female contains much more water than that of the cow, and is, consequently, thinner, and less opaque. Cow's milk also contains nearly twice the amount of butter, while the proportion of sugar and soluble salts is nearly the same.

When an infant is unfortunately deprived of its natural sustenance, and cow's milk has to be substituted, it must be "let down" by the addition of water, and the reduction in sweetness compensated for by the admixture of sugar. From whatever source obtained, milk contains every constituent required by the human body for its growth and nourishment; and nothing more is required for the development of the young of all mammals, whether carnivorous or herbivorous, than the elements which analysis shows us to exist in that important fluid.

It would be erroneous, however, to suppose that milk, on account of its composition, would be a sufficient diet for the adult animal. The acquisition of teeth sufficiently demonstrates the necessity for solid food. When the strength of the digestive organs becomes increased, and the tone of the general system improved, food is required which will give the stomach work to do commensurate with its enlarged powers. The teeth are ready to break it up; the action of the teeth causes a flow of saliva, which, mixing with the food during mastication, prepares it for the juices with which it is afterwards to come in contact in the stomach, and finally, the gastric juice, bile, and pancreatic fluid complete the solution of the mass.

The more general use of milk, however, as a beverage by adults, would be attended with much benefit to health. Beer, on an average, contains but one per cent. of nutritive matter, while milk, as the above table points out, contains nearly twelve per cent. All its valuable constituents would be utilised, and its freedom from alcohol would be an advantage of incalculable value. We should perhaps be ridiculed if we were to recommend the use of milk at the dinner-table; but at that meal we really require no beverage whatever, and digestion would be effected much more easily and comfortably without the dilution produced by imbibing large draughts of beer or wine, all of which must be absorbed before the gastric juice can efficiently act on the solid mass. The substitution of milk for tea and coffee, however disagreeable the change would be to most people, would, in general, be productive of benefit. At any rate, children under twelve

years of age should not be permitted to take either of these beverages, as they undoubtedly affect injuriously the nervous system, while the high temperature at which they are generally drunk is another cause of debility and subsequent dyspepsia.

The importance of being able to obtain daily a supply of pure milk can hardly be over-estimated. The continued use of milk from which the cream has been abstracted, or that of ill-fed or unhealthy cows, cannot fail, in the long run, to be productive of serious injury, especially in the case of children brought up by hand.

The reputation of the London "sky-blue" is deservedly bad. London milk is generally the produce of cows that, kept altogether in sheds or yards, become emaciated, if not diseased, from the want of pure air and fresh grass. The milk they supply is bad enough, but it is still further let down by a liberal proportion of water, so that when it is left to stand for the usual time, we fail to notice anything but a mere trace of cream. It is a matter of some importance that we should have at hand some simple means for testing the quality of milk, and thus be able to protect ourselves from imposition, and our children from injury.

An instrument called a *Lactometer* has long been in use to test the quality of milk. It consists of a glass stem, with a bulb at the extremity weighted with mercury to enable it to float upright in the liquid to be examined. It is a kind of hydrometer used for determining the strength of spirits: the lighter the liquid in relation to water, the deeper the bulb will sink; and the heavier it is, the higher the instrument will be buoyed up. The stem is graduated into 100 degrees, and so weighted as to sink to a mark in pure water—in milk, which is heavier than water, the stem will rise in proportion to the density; the density varies according to the amount of solid matter contained in the liquid. If the specific gravity of water be taken at 1,000°, the specific gravity of milk ought to be 1,030°; while that of cream is only 950°. The mark indicates the level of the instrument in pure milk.

The indications of the lactometer, however, are not, in all cases, to be relied on, as a large quantity of cream will lower the specific gravity in the same way as the addition of water; and a milk unusually rich in cream is made to appear adulterated. The best method of testing milk is to employ, in conjunction with the lactometer, a glass vessel called a "cream-measurer." It is provided with a foot, and graduated from 1 to 100. Being filled with milk, it is left undisturbed for twelve hours, and the quantity of cream can be read off. If less than 10 per cent.—that is, ten divisions of the scale out of the hundred—the milk may be considered too poor for use. A rich milk contains as much as 12 per cent. of cream, while one containing less than 8 per cent. has certainly been watered.

With regard to calves' brains and chalk, with which the London milk is popularly associated, little need be said. The first would be an expensive and altogether impracticable source of adulteration, and the second, by its insolubility and subsidence, soon tells its own story.

## STRIKING A LIGHT.

By John Mayer, F.C.S., etc.

THE operation known as "striking a light," while it is one of the most familiar things of common life, has varied in a remarkable manner from age to age in the progress of mankind up to the present stage of civilisation. In every form, however, it is accompanied with most interesting, if not even beautiful phenomena, all of which are illustrative of very important principles in the sciences of chemistry and physics. Let us, in the first instance, note that method of "striking a light" which has become quite universal amongst civilised nations during the last forty years or so; in short, let us strike a lucifer match, observe what takes place, and strive to explain the "why and because" of what we see, in the hope that what we incidentally learn in this first part of our inquiry may lead us to understand the scientific principles involved in some of the other and less familiar modes of obtaining more or less instantaneous light.

In its most familiar form, a lucifer * match is a square splint of soft yellow pine, $2\frac{1}{4}$ to $2\frac{1}{2}$ inches long, and $\frac{1}{10}$th to $\frac{1}{8}$th of an inch in thickness. It is tipped at one end with a small mass of somewhat hard material, whose colour—blue, red, &c.—varies with the whim of the manufacturer, or with that of

* Latin for "light-bearer."

the customer for whose wants and tastes he caters. If examined a little closely under a strong light, and more especially with the aid of a pocket lens, it is seen to contain small particles which have a glistening appearance. Although the material forming the club-shaped extremity of the match is usually almost entirely destitute of odour, yet, when gently rubbed against bodies which exert a definite resisting power, it emits a somewhat garlic-like odour, thus showing that a certain amount of chemical change has been effected. By employing a more decided force—sharply rubbing the material against a rough surface, such as the sand-paper which is specially provided on the outside of the match-box—we find that the match at once bursts out into flame, in which both heat and light are developed in a very marked manner. By watching the flame closely at the earliest stage, it is just possible that we may notice a faint violet-colour in it. Of this more anon. Before the flame of the match-tip has ceased to dart forth, flame is also imparted to another material which forms an important constituent of our lucifer match; in this instance, however, there is no violent detonation or deflagration, as in the first stage of the burning operation, and, instead, there is a quiet, steady, and luminous flame, which is likewise soon imparted to the wood of the match-splint itself. It may be that the second stage through which the flame passes is accompanied with a blue coloration and a very decided smell, such as are familiar to us when we ignite common brimstone or sulphur; but nowadays such phenomena are not usually observed in striking a match, inasmuch as sulphur—with which common lucifer matches were invariably coated for a short distance from the end—is no longer used in their manufacture, or, at all events, is used only to a very limited extent. Let us strike another match, and note very carefully the second and third stages in the progress of the flame, assuming, of course, that our experimental match has no yellow coating indicative of sulphur. In the second stage, more especially, the flame is very luminous and rather smoky, and as it passes into the third stage—that in which the wood becomes ignited—we shall very probably notice that there is a clear liquid body on the surface of the wood, which is chased along the splint by the flame—sometimes, it may be, to a distance of one, one and a half, or even two inches before it is finally dissipated.

Now, if we have carefully noted all these facts and phenomena, we are in a position to understand the science or philosophy that is involved in one of the most familiar acts of our daily life—namely, that of "striking a light." It would be well, however, that we should also notice another very important fact in the production of an instantaneous light by the use of a lucifer match: it is, that the match may be lighted by the employment of percussion, or sudden compression, instead of friction. Every boy knows that he can ignite an ordinary lucifer match by laying it upon a hard resisting body, such as a brick, a block of sandstone, an anvil, &c., and then striking it sharply with a hammer; or by laying it down on a dry pavement and then suddenly bringing the heel of his boot down upon it. Still, our explanation of the "why and wherefore" of the production of light by striking a match may be all the better understood if we indicate one or two more illustrative experiments. Let us take a small pellet of the chemical element known as phosphorus,* duly observing the precaution to have it made as dry as possible by simple pressure between folds of blotting-paper. We lay it on an anvil or a smooth flagstone, and in close contact with it we lay a small crystal or fragment of chlorate of potash, and then we apply the sharp stroke of a hammer, the result being a very decided explosion, the violence of which will vary with the amount of material used.† Instead of phosphorus we may use a very small pinch of flowers of sulphur, and by means of a wooden spatula, or bit of cardboard, make a mixture of it with a little pulverised chlorate of potash. By firmly rubbing or triturating this mixture in a strong porcelain or iron mortar we again get a more or less powerful detonation. In both cases the detonation is attended with flame.

Phosphorus and sulphur are two of the most easily-ignited substances in the whole range of the chemical elements; but limiting our attention in the meantime to the former of these, we may mention one or two examples of the extreme facility with which we may generate light by its use: we shall not say "*strike* a light," from the very fact that, in the experiments to be indicated, friction, percussion, and compression are absolutely unnecessary. If we lay a small pellet of carefully-dried phosphorus on a plate or a brick, and then cover it with a few small crystals of iodine—which is another of the chemical elements, but not a combustible body—we shall find that the former almost instantaneously becomes ignited, and burns with a white,

* Greek for "light-bearer."

† Let me impress on my readers the desirability of using only the smallest quantities of these materials.

smoky flame. Again, if, by means of a deflagrating spoon we introduce a bit of dried phosphorus into a jar of chlorine gas, a similar kind of action ensues in a very brief space of time; flame and white smoke are produced, as before. But it is not even necessary to use either of those powerful chemical elements, chlorine and iodine, in order to set phosphorus alight. A bit of dry phosphorus is distinctly luminous in the dark; and if two or more sticks of dry phosphorus be permitted to remain in simple contact for awhile, they will eventually burst into flame quite spontaneously, even at the normal temperature of the air; and the action will be much more rapid if the phosphorus be exposed in the air to the influence of the direct rays of the sun. Furthermore, if we pour a few drops of a solution of phosphorus in bisulphide of carbon * upon a sheet of blotting-paper, the following series of phenomena may be observed:—The solvent liquid, owing to its remarkable volatility, will become dissipated in the course of a few seconds; the phosphorus previously held in solution will then be seen as a thin white deposit on the paper; a faint white smoke, such as we are already familiar with, will begin to show itself; and while we are looking at it the paper will become enveloped in a very smoky flame, and be left as a black, charred mass wherever it was previously wetted with the phosphorus solution.

All these results, which in imagination we have been observing, are due to the operation of the force which has been called Chemical Affinity. In each of the two last-mentioned cases the spontaneous ignition or combustion of the phosphorus is brought about by the chemical action of the oxygen gas, which is the active ingredient of the air we breathe, and is due to the affinity or liking of the two elements for each other. The action, known in these two cases as *oxidation*, is slow at first, but as it progresses the heat gradually increases, and by and by it is raised sufficiently high to ignite the combustible element. And here we may state, as a general law, that whenever two or more bodies enter into chemical union, heat results, and it may also be attended with the evolution of light. Then there is the case of the phosphorus and iodine. Both of those bodies have a sort of chemical love for each other, and they gradually act and re-act upon each other when they are brought into contact—heat, as before, being generated. In this instance, however, the heat which arises becomes so great that the remaining phosphorus bursts into flame, and burns at the expense of the atmospheric oxygen, while the remaining iodine passes rapidly away as a vapour, having a beautiful violet-colour, which is one of its physical characteristics. Lastly, we have the case of the phosphorus in the jar of chlorine gas. Those elements are specially prone to unite when they are brought within the range of their chemical affinity, spontaneous ignition of the former being the physical result, and a definite compound of the two elements being the chemical result.

We have now arrived, I think, at that mental stage in which we can understand the philosophy of "striking a light" by the use of a lucifer match. For the last forty years or so the rule almost universally observed in the manufacture of lucifer matches has been to employ phosphorus in the composition or mixture with which the ends are tipped; and there is good reason for believing that, although that remarkable chemical element had been discovered so far back as the year 1669, it was not used in the production of instantaneous lights as an article of commerce until about the year 1833. According to the late Professor Faraday, the first maker in this country was John Walker, of Stockton-on-Tees. There were various methods known long prior to that year by which ready lights could be obtained, most of them being due to the progress made in chemical science; however, for the present, we have got nothing to do with them. As we have already said, even very gentle friction will develop some chemical change in the match composition; and by employing more decided energy we bring about ignition, which is at first very active. In this action we take advantage of the phosphorus which is contained in the composition, in which there is always at least one other essential ingredient—namely, some chemical compound which contains a large quantity of oxygen which may readily be pressed into service to maintain the combustion of the phosphorus. Of course, there are other materials, one of which—glue, or gum—is used as the adhesive substance to bind all the solid bodies closely together. The highly-oxidised chemical compound just referred to, which is generally used in the ignition composition by the match manufacturers of this country, is chlorate of potash, from which an abundant supply of oxygen may easily be obtained; by many of the Continental manufacturers, however, nitrate of potash (common nitre or saltpetre), is used as the source of

* This solution has in recent years been spoken of under the name of "Greek fire." It is said to have been the substance used under that name at the siege of Charleston in 1863.

the oxygen necessary for maintaining the combustion when once it is started. That either of these substances is a ready source of that element may easily be demonstrated by throwing a few crystals of it upon an incandescent coal-cinder or piece of wood-charcoal, most active combustion being the almost instantaneous result; and the faint violet-colour of the flame which is observed may be taken as tolerably good evidence that some potassium compound is being used. In some instances peroxide of lead, or oxidised red lead, is used as the source of the oxygen, more especially for what are termed "silent matches"—so dear to the burglar's heart. Besides the combustible material, the compound containing the supporter of combustion, and the gum, or glue, there is not unfrequently a colouring body used in making up the ignition-mixture: it may be smalt, ultramarine, or Prussian blue, or magenta, vermilion, Venetian red, Persian red, &c. But there are also the small glistening particles to which we referred in an early part of this paper. They are minute granules of ground glass, the function of which seems to be assisting the glue to give a firm body to the ignition-mixture, aiding to protect the fine particles of phosphorus from the influence of the oxygen in the air, and aiding to generate a higher temperature than there would otherwise be. The result last referred to is probably due to the formation of new compounds with the potash or other mineral base that may be present in the mixture. In many instances manufacturers use other ingredients in making up their respective ignition-mixtures, some of which are additional oxidising compounds, others supplying carbon in a fine state of division, while others give bulk, and only play a sort of mechanical function, instead of a chemical one. Whiting or ground chalk is an example of the class of substances last referred to.

It is not necessary that we should enter into any detailed account of the exact quantities of the respective ingredients used by different manufacturers of common lucifer matches, or of the mode in which the ignition-mixture is prepared. Those are things which are generally regarded as "trade secrets," into which we have no need or inclination to pry; and it is practically sufficient for us to know the important leading fact in the chemistry of an ordinary lucifer match that the material from which the initial light or flame is obtained contains, as its essential constituents, phosphorus and some chemical compound which is rich in oxygen, and glue, gum, &c., to bind them together. It may be desirable, however to make a few remarks in regard to the manner in which the phosphorus is dealt with in preparing the inflammable composition, as also in regard to the quantity used. Assuming that glue is the binding-substance used, we first dissolve it in water to the consistency of a thin syrup, which is raised to a temperature of from 140° to 150° of Fahrenheit, when the phosphorus (which very soon melts) is gradually added in the requisite quantity, the mixture being stirred the while until a perfectly uniform emulsion is obtained. The other ingredients, previously reduced to fine powder, are added in successive quantities, and carefully mixed until a uniform pasty mass results. One of the directions in which improvement has been carried in recent years is the reduction of the amount of phosphorus used to the lowest possible minimum. Of course, as has already been indicated, phosphorus is rather a dangerous substance to deal with, and hence it is very undesirable that it should be used in excessively large quantities in making the match-tipping mixture. On the other hand, too small a proportion may be used, although there is less likelihood of erring in that direction. If, as in the manufacture of gunpowder—which is likewise a mere mechanical mixture, and not a definite chemical compound—the essential ingredients of the inflammable composition could be proportioned in such quantities as would agree with the doctrine of chemical equivalents, a tolerable approach to perfection in this important chemical art would be attained. Again, it is of the utmost importance that the phosphorus should be got into as fine a state of division as possible. By reducing it to an infinitesimally minute state of sub-division, the utmost economy in the manufacture is obtained, and then there is a tolerable certainty of it being impossible to commence friction at any portion of the match-tip without finding particles of the combustible material, phosphorus, in (practically) absolute contact with the oxygen-supplying compound. Now, the most minutely divided phosphorus that we know of is that which is prepared by dissolving ordinary phosphorus in bisulphide of carbon, a process already referred to; and by using that substance prepared in the way just mentioned, it is possible, according to the results of investigations made some years ago, to reduce the proportion of phosphorus to $\frac{1}{30}$th of that which was then in common use. In recent years, however, much improvement has been made in the manufacture of lucifers, without, I believe, that process of obtaining

molecular sub-division of the phosphorus being resorted to. In a recipe given by a well-known German chemist some years ago, I find the proportions of phosphorus set down as $\frac{4}{27}$ths of the weight of the whole ignition-mixture. In another instance it forms $\frac{3}{24}$ths, or $\frac{1}{8}$th of the whole; in a third there are 8 parts of phosphorus in 77·4 parts of the ignition-mixture, or rather more than $\frac{1}{10}$th of the whole; and it has recently been stated that the best proportion is from $\frac{1}{16}$th to $\frac{1}{12}$th of phosphorus. Some idea of the average quantity present in the ignition-mixture of a single match may be formed when we mention that, according to Professor A. W. Hofmann, the annual consumption of phosphorus in a Bohemian match-factory some years ago was $6\frac{1}{2}$ cwt. of phosphorus for 200,000 boxes, each containing 5,000 matches. According to M. Hochstätter, of Langen, 15 grammes of the ignition-mixture, containing 7 per cent. of phosphorus, suffice for the coating or tipping of 1,000 matches; and according to M. Pollah, 31 grammes of a mixture with the same percentage of phosphorus are required for the same number of matches. The discrepancy shown in these quantities is quite intelligible when we remember that the matches made by different manufacturers may vary in size very much. Lastly, we may mention that a very eminent authority on the production, properties, and uses of phosphorus, Dr. Anton von Schrötter, of Vienna, calculates that 1,200 tons of that substance are consumed annually, almost the whole of which is employed in the match-trade, the total supply being furnished by two establishments—namely, those of Albright and Wilson, of Oldbury, near Birmingham, and Coignet and Son, of Lyons.

Having got this highly-inflammable mixture ignited, we must now look for a brief space at the next stage of the operation of "striking a light"—namely, the ignition of the material which forms the intermediary or internuncio between the more and the less combustible bodies, and which eventually imparts flame to the splint of wood. For a good many years after phosphorus matches came into general use, the inflammable substance employed as the fire-conductor was sulphur, which has already been referred to as being very easily ignited. Into this substance, in the molten condition, bundles of the splints were dipped to a depth of rather more than a quarter of an inch, so as to give the wood a thin coating of that body. But burning sulphur generates a gaseous compound which possesses a very objectionable smell, and with the view of getting rid of that disagreeable result of "striking a light," a very great improvement was effected, in the year 1861, by Mr. R. M. Letchford, a well-known London manufacturer of lucifer matches. Various manufacturers had endeavoured to avoid, as far as possible, the use of sulphur for the purpose of communicating to the wood the combustion commenced in the ignition-composition, by replacing that substance by wax, or stearic acid, which could only be used, however, for the higher-priced matches. But by Mr. Letchford's process it was rendered possible to use a substance which has since become very cheap, and which is now almost exclusively used in this country instead of sulphur. The material in question is solid paraffin, or paraffin oil; but I believe that the kind of paraffin which is used is the ordinary "paraffin scale" of commerce, a substance which can be had in any desired quantity, at a price which is fabulously cheap when we consider that the first specimen of paraffin publicly exhibited dates no further back than the Great Exhibition of 1851. Its price is now only about 3d. per lb., or quite as economical as sulphur. The solid paraffin is melted, and the ends of the matches, previously set a short distance apart in frames, are dipped into the liquid, which is very readily absorbed by the soft, dry splints, the ends of which have previously been heated. It was to this substance that we previously referred when we spoke of a clear liquid body running up the surface of the burning match-splint, for so long as the match remains at the ordinary temperature of the air, the paraffin, absorbed into the pores of the wood, remains practically invisible. It burns with great regularity, and without any objectionable smell.

Another improvement in the chemistry of lucifer matches, and one which dates further back than Letchford's patent process just referred to, was the substitution of "amorphous" phosphorus for the common or "vitreous" variety, as it is sometimes called, and which was based upon a very remarkable discovery, made so far back as the year 1848. The "allotropic" modification known as red or amorphous phosphorus, which had been observed to result when ordinary phosphorus was exposed to the action of heat under peculiar conditions, was most carefully investigated in that and subsequent years by Schrötter, of Vienna; and the result of his experiments and observations was that it possessed chemical, physical, and physiological properties vastly differing from those which were known to belong to the ordinary variety of that element.

The latter, when present in the ignition-mixture, not only takes fire very readily by friction and percussion, and by a moderate elevation of temperature, but it is also soluble in some of the digestive secretions, and forms an irritant poison; besides which it yields a vapour during the process of manufacture which acts most detrimentally upon the health of the work-people if it is inhaled in any marked quantity. It was in course of time discovered that the red or amorphous phosphorus suffered no change in the air, even when exposed in it over long periods; that it was absolutely incapable of ignition by friction, and therefore portable without danger; that it possessed no taste or odour, and was insoluble in all liquids which dissolved ordinary phosphorus, and consequently not poisonous; and that it required a very high temperature before it would ignite. Though it no longer possessed the ordinary properties of the phosphorus with which chemists had been so long familiar—namely, volatility, fusibility, and inflammability at comparatively low temperatures—it was absolutely the same chemical element, but in a totally different physical condition. The distinguished Vienna chemist also showed that the amorphous variety might with great advantage be substituted for common phosphorus in the match manufacture. Scarcely had these and the other correlative facts been made known than attempts were successfully made to turn them to account, for in the Great Exhibition of 1851, excellent lucifer matches were shown by Messrs. Dixon, Son, and Co., of Manchester, the ignition-mixture of which contained Schrötter's phosphorus as its special ingredient; but they never seemed to find favour with the public, and they soon disappeared entirely from the market.

There was still an ardent hope, however, that amorphous phosphorus would yet be used with success in making lucifer matches, and accordingly a patent was taken out very early in the history of that substance (1851) by Mr. Albright, of Birmingham, for a process by which it might be prepared on a large scale. Friction-matches, themselves containing no phosphorus, but involving the use of that element in its amorphous condition, were made and sent into the market in the year 1854, and in the following year they were shown in the Paris International Exhibition by no fewer than three firms, all of whom, however, were Continental manufacturers. Considerable chemical interest attaches to these so-called "safety"-matches, and therefore they call for one or two remarks. Having some of them at hand, we take one and sharply draw the club-shaped tip over any ordinary rough surface, but we find that this attempt at "striking a light" is altogether futile; and after using up several of the matches we at last try one of those still remaining upon the sand-paper fixed on the box, when the desired light is obtained. How shall we explain this circumstance? On making a chemical analysis of the ignition-mixture on one of these matches, we find that its main ingredients are chlorate of potash and sulphide of antimony, with glue as the binding material. Now, a mixture of those two chemical compounds in certain proportions, and both in the form of dry powder, will detonate with great violence by using even a moderate amount of friction, and especially if struck sharply with a hammer; but as the special ingredients of a match-tipping mixture, their power of chemically reacting upon each other is suspended by the presence of the glue. Then, again, if we carefully examine the sand-paper on the match-box, we find that it is specially prepared, and that in addition to the sand there is a quantity of amorphous phosphorus in admixture with black oxide of manganese, or sulphide of antimony, the binding material again being glue. Simple frictional contact of the match with the amorphous phosphorus *rubber* on the box easily and certainly induces ignition in the former, which is almost instantaneously communicated to the paraffin underneath the ignition-mixture. These "safety"-matches, which "only strike on the box," and are so familiarly associated with the names of "Bryant and May," have never got into general use in this country, notwithstanding their "safety" character and the non-poisonous quality of the phosphorus used in preparing the paste for the special friction-surface. The ignition-mixture of Swedish "safety"-matches* has been found to contain chlorate and bichromate of potash, red lead, and sulphide of antimony; and with such matches "striking a light" is easily effected on a surface prepared with 8 parts of amorphous phosphorus and 9 parts of sulphide of antimony.

It is possible that in course of time the consideration of the question forming the main subject of the present paper—namely, the chemistry of a lucifer match—may no longer involve the function performed by phosphorus in the process of "striking a light," inasmuch as recent experimental investigation has tended in the direction of dispensing with that element altogether. For that purpose various non-phosphoric ignition-mixtures have been

* In Sweden and Denmark the use of the ordinary kind of matches is prohibited.

suggested, some of them being very complex in their composition. One mixture which is said to produce lucifer matches of good quality contains only chlorate of potash and hyposulphite of lead, bound together on the match-splint in the usual way; but in the meantime there is no immediate prospect of phosphorus being superseded.

Prior to phosphorus coming into use for the manufacture of lucifers, which is an event quite of our own time, there were in operation various other methods of "striking a light," to which we must now briefly devote some consideration. One of the chemical matches which in historical order almost immediately preceded the true lucifer, was that known as the "Congreve" match, named after Sir William Congreve, the distinguished artillery officer. It was a flat wood splint, tipped with sulphur, upon which there was fixed a mixture of chlorate of potash (1 part) and black sulphide of antimony (2 parts). Many of us have vivid recollection of the "Congreves," for they were the first true friction-matches. For the benefit of those who do not remember them, it may be stated that the act of striking a light by their aid was effected by vigorously and sharply drawing the match-tip between two pieces of sand paper or emery-paper held firmly between the thumb and first finger. The philosophy of the process lay in the fact that the sharp friction of the mixed potash and antimonial compounds generated heat enough to produce ignition, which was subsequently communicated to the sulphur, and then to the wood splint. Immediately before the "Congreves" there were the "Prometheans," whose career was only short-lived. Their value as instantaneous lights was due to the circumstance that a mixture of chlorate of potash and sugar (a compound rich in carbon) at once deflagrates if touched with a drop of strong sulphuric acid, owing to the liberation of a gaseous compound of chlorine and oxygen, which may be regarded as a supporter of combustion. These chemical matches consisted of a kind of paper cigarette, to which was fixed a small quantity of the sugar and chlorate composition, and in which there was a small glass bead or globule containing sulphuric acid. The breaking of the latter, by compressing the match with a pair of pliers, or between the teeth,* liberated the acid, which at once performed its chemical function. The "Promethean" was in the direct line of descent from another chemical match, one which seems to have been invented in Vienna (a city still famous for its connection with the match-trade) as far back as the year 1812. It also was a sulphur-tipped wooden splint, and the ignition-mixture with which it was covered was one consisting of sugar and chlorate of potash, the firing of which was effected by immersing the match-tip in strong sulphuric acid kept in a small phial, or absorbed into a quantity of asbestos. At or about the same time that matches of this kind were before the public—known as "oxymuriate" matches—phosphorus was also used in procuring instantaneous light. The method referred to was to fuse small quantities of phosphorus and sulphur together in a small glass test-tube immersed in hot water, and the tube was afterwards closed with a cork; then, when a light was desired, a thin splint of wood was immersed in the fused mass and withdrawn, ignition being effected by the gentlest friction, even on the cork used to close the tube. This mode of "striking a light" is based upon the principle referred to in one of our former experiments, and much care requires to be taken by those who resort to it.

Not the least interesting method of obtaining an instantaneous light by chemical means was that illustrated by the so-called "philosophical lamp," devised in the early part of the century, by Dr. Johann Wolfgang Döbereiner. It consists usually of a cylindrical glass vessel, about six inches high and four inches in diameter, in which, attached to the under surface of the movable metallic lid, there is hung a bell-shaped glass, which reaches rather more than half-way down, while there is hung inside it a mass of metallic zinc. Above, the bell-shaped glass becomes tubulated, and at pleasure an opening can be effected between the tubed portion and the external atmosphere. Now, by filling the glass vessel fully half-way up with water, and then introducing the bell-shaped glass, it is evident that, if the little tap is closed, the air in that glass will be under a certain degree of pressure. Let the tap be opened, however, and the contained air will rush out until the water rises to a uniform level both inside and outside the bell. If the water is now acidulated with sulphuric acid, chemical action will be set up, the zinc liberating a quantity of hydrogen gas, which will accumulate in the bell; and by turning on the small tap, that gas, hitherto under pressure, will rush out, and will burn if a light is applied to it. But instead of lighting it in that way, let us

* The man who thus struck a light with the first "Promethean" seen in Cornwall had reason to regret it. The superstitious tin-miners before whom he carelessly exhibited the new chemical toy were no doubt sufficiently impressed with the wonder, for they dragged the chemist thrice through a pond as a wizard. But ever afterwards he was rather prejudiced against *al fresco* popular demonstrations on the curiosities of science.

place a small mass of metallic platinum, in its spongy condition, within a short distance of the escaping jet of hydrogen. Almost instantaneously, the platinum sponge will begin to glow and become brilliantly incandescent, and the jet of hydrogen will then take fire and burn with its comparatively non-luminous flame. Following Döbereiner's instructions, we have struck a physical light from certain apparently unpromising materials; and for the benefit of the uninitiated, we shall now throw a little mental light upon the process by which it was struck or obtained. Let it be observed, then, that spongy platinum has the peculiar power of abstracting oxygen gas from the air, and storing it up in its pores in a highly concentrated form. If that gas and hydrogen be brought within the range of their chemical affinities, union will ensue with more or less energy. In this case, the hydrogen finds the oxygen in such a condition as to favour the immediate union of the two elements; heat results from the chemical union, and very shortly it reaches the condition of bright, glowing incandescence which is necessary for the ignition of the still escaping jet of hydrogen gas. This lamp is even yet in occasional use on the lecture-table of the professional chemist, and it is a beautiful example of the application of science in our endeavours at "striking a light" (Fig. 1).

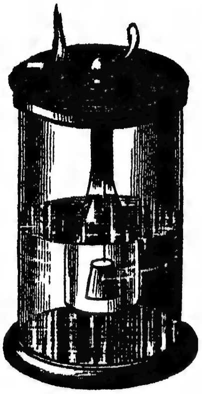
Fig. 1.—Döbereiner Lamp.

The use and value of the somewhat classical flint and steel in "striking a light" have long been known, although the practical employment of the process referred to is somewhat unfamiliar to the present generation. Every boy knows, however, that he can call forth at pleasure a brilliant shower of fiery sparks from a dry pavement of coarse sandstone or rough asphalte, providing that his shoes or boots are well shod with iron or steel. Such showers are frequently seen when a powerful horse vigorously sets his shoulders to the work of drawing a too-heavy load over slippery granite or whin paving-stones. Copious sparks of fire are also frequently seen during dark nights on the flinty roads of Hampshire, Sussex, Kent, or Surrey, when they are traversed by the labourers with their rough hobnailed boots. In these, and many other more or less similar instances, the process of "striking a light" admits of a thoroughly scientific explanation. It is simply friction, or rubbing together. Draw the hand rapidly along the table, or down the sleeve of your coat, and heat will be felt. Rub any two hard substances—or, indeed, any solid substances—together, and there will also be heat. If the operation is continued with sufficient energy, the heat will increase in intensity until it is visible in the form of "fire." It is this which is displayed when the flint is struck against the steel, or against another piece of flint. To put it briefly, it is that the mechanical energy exerted in producing the friction is transformed into heat, which actually becomes so intense as to set fire to the minute particles of iron or steel that are separated from the mass by the violence of the action. Of course, there must be oxygen gas present, otherwise no sparks of light will be emitted at the moment of exerting the friction. If flint and steel be struck against each other in a vacuum, there is no light produced, but the particles of steel thrown off, if afterwards examined by the aid of a microscope, show distinct signs of having been in a molten state. But in order to get a permanent light from the evanescent shower of sparks just spoken of, it is necessary that the incandescent particles of steel should be allowed to come into contact with easily-ignited material, which will burn slowly—such a substance, for example, as the tinder which is produced by the imperfect combustion of linen or cotton rags, or, better still, the substance called amadou, or German tinder, which is a peculiar preparation of several species of fungi (mushroom order), belonging to the genus *Polyporus*. This smouldering tinder may then be touched with a sulphur-tipped wooden splint, which at once bursts into flame (Fig. 2).


Fig. 2.—Tinder-Box—Flint and Steel—Brimstone-tipped Matches.

But it is not even necessary to use the steel at all, as it is quite possible to get light by friction in even a less promising way. For example, it is even possible to render two quartz pebbles distinctly luminous by rubbing them together in the dark; then, again, if a small rock crystal have one of its faces briskly drawn over the face of a large crystal of the same material, both heat and light are produced. On the authority of a gun-flint maker, it has been stated that flint chips, if thrown violently down upon which has been well dried and vigorously rubbed between the hands; and the aborigines of certain parts of Eastern Asia, and especially of the islands of Borneo and Sumatra, obtain it by striking together two pieces of split bamboo. Of course, it should be noted that amongst the woody tissue of a bamboo stem there are deposited myriads of small crystals of quartz, and thus the method in question does not seem so very extraordinary.

It is not necessary that we should enlarge upon

Fig. 3.—Tasmanian Savage obtaining Fire.

touch-paper* lying on a flagstone, will develop such an amount of heat as will induce ignition in that combustible material; and from this it may be inferred that there will not be much difficulty in "striking a light" if two flint-stones, with good edges, be violently struck against each other over a mass of dry moss on which sulphur is thinly scattered in very fine powder. Many primitive tribes of mankind obtain fire by somewhat similar means. The wild Eskimo generally obtain it by striking pieces of quartz and iron pyrites together, allowing the resulting sparks to fall upon moss

* Touch-paper is made by immersing bibulous paper (like blotting-paper) in a strong solution of nitre, and then drying it carefully.

the purely mechanical operations of preparing the match-splints, but it may not be undesirable to mention two or three facts by way of indicating the extent to which inventive genius has been pressed into service in designing ingenious machinery for this branch of manufacture. To go back no further than the Great Exhibition of 1851, we find that one of the most improved machines then in use was capable of cutting 1,000,000 splints in four hours. About the same time a machine was in use in Saxony by which 3,000 splints were made per minute. Some time ago Mr. Charles Tomlinson described a London match-factory where the splint-cutting machine turned out 2,500,000 matches daily; while at Messrs. Dixon's factory,

near Manchester, the daily produce was said to be from 6,000,000 to 9,000,000, but whether or not that was the produce of only a single machine is not stated. One of the most productive machines at this kind of work is capable of cutting from 10,000,000 to 16,000,000 of matches per day—a number which, if laid end to end, would reach upwards of 600 miles. It is in use at the Greenvale Chemical Works, Glasgow, and was invented by Mr. John Jex Long, who has been engaged in the match-trade for fully a quarter of a century, and now employs from 300 to 400 workers in producing matches and "vesuvians" alone.

But fire may also be obtained by the sudden compression of air in a confined space containing some very combustible material. For this purpose the beautiful experiment with Mollet's pump, or the ordinary fire-syringe of the lecture-room, may be employed. It consists of a small metal or glass cylinder, in which a closely-fitting, solid piston works. It is readily noticed that heat is developed by rapidly forcing down the piston in the cylinder, and if a small bit of German tinder be fixed to the piston and the action then be performed, the tinder will be ignited sufficiently to inflame a sulphur match. If, instead of the tinder, a pellet of cotton-wool be used which is moistened with ether or bisulphide of carbon, a flash of light may be obtained inside the cylinder, and can be seen, if the latter is made of glass (Fig. 4).

Of the many varied methods of employing friction to obtain fire among savages in both hemispheres, we have left ourselves no room to speak with any detail; but a simple experiment may indicate how such people may turn the principle to account in their native homes. First, let the reader note the effect produced by the rapid friction of a flat brass button against a piece of soft, dry wood—an old and familiar experiment. Then let him take a bit of dry wood a few inches long, and rub it vigorously by one end upon a wooden surface, say a clean, dry floor. In a very few seconds the heat developed will be sufficiently great to ignite a pellet of dry phosphorus if the rubbed end of the stick is simply laid against it. Primitive tribes certainly do not possess phosphorus as one of their conveniences, but they have the wherewithal to produce light if they possess any wood, and particularly if they have both hard and soft woods. As an example of the mode of getting fire by rubbing two pieces of wood together, we may quote the following, by Captain Drayton, regarding the Kaffirs of South Africa :—

"Two dry sticks, one being of hard and the other of soft wood, were the materials. The soft stick was laid on the ground, and held firmly down by one Kaffir, whilst another employed himself in scooping out a little hole in the centre of it with the point of his assagy; into this little hollow the end of the hard wood was placed, and held vertically. These two men sat face to face, one taking the vertical stick between the palms of his hands, and making it twist about very quickly, while the other Kaffir held the lower stick firmly in its place. The friction caused by the end of one piece of wood revolving upon the other soon made the two pieces smoke. When the Kaffir who twisted became tired, the respective duties were exchanged. These operations having continued about a couple of minutes, sparks began to appear, and when they became numerous were gathered into some dry grass, which was then swung round at arm's length until a blaze was established; and a roaring fire was gladdening the hearts of the Kaffirs, with the anticipation of a glorious feast, in about ten minutes from the time that the operation was first

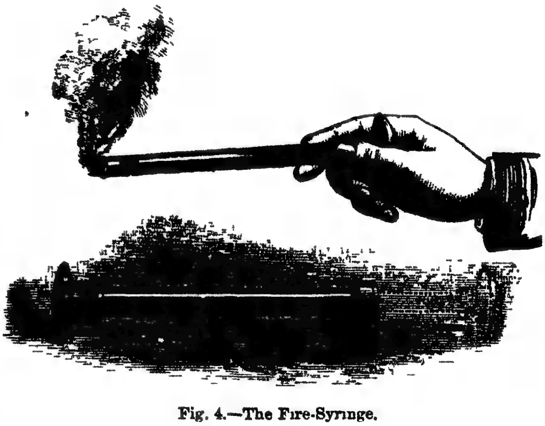

Fig. 4.—The Fire-Syringe.

commenced." The same description will apply to the fire-drills of many other savage tribes throughout the world (Fig. 3).

In various instances travellers have given us drawings of such primitive methods of "striking a light,' especially those involving the use of fire-drills, the stick and groove, &c.; and some philosophers have seriously discussed the question of portions of the human race never having known how to produce fire; but on that point we are not in a position to say anything that would be of value in the discussion, and we shall therefore leave it to the philosophers.

# THE MIGRATIONS OF BIRDS.

By A. Leith Adams, F.R.S., F.G.S.,

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THERE are few more interesting and improving studies in connection with the natural history of animals than that which deals with the social habits of the feathered tribes. It is an inviting field of inquiry in several respects, but more especially with reference to such birds as are called *migratory*, in consequence of a disposition to change their retreats at certain seasons.

But, although this habit or instinct is highly developed in birds, it is not altogether confined to them, inasmuch as many other animals perform similar movements; but their migrations are neither so extensive, nor are their concomitant phenomena so interesting and instructive. The subject recommends itself to our notice at the present season, when the sweet messengers of spring are commencing to put in their appearance, and gladden the landscape with their joyous songs. We propose, therefore, to consider a few of the more inviting points of inquiry relating to the nature and causes of these migratory movements.

The simplest conception of migration, as applied to the lower animals, is the abandoning of the summer retreat through failure of food. This might be further illustrated by the following occurrences, which take place every winter in our own islands. No sooner do the cold months set in, than many birds, such as certain ducks, the Woodcock, Fieldfare, and other residents of more northern countries, put in an appearance; whilst not a few of our native birds seek the milder climate of the south, and even a good many cross the English Channel, including such familiar songsters as Redbreast and the Skylark.* Now, so far as these movements are concerned, there is little to excite our wonder or astonishment, considering that they are the direct results of climate affecting the food-supplies, which for the most part consist of vegetable substances; at the same time, not a few of these birds subsist also on insect food, when procurable; so that, if a purely insect-feeding bird should by any chance acquire a taste likewise for vegetable food, it would be enabled to remain longer in autumn, and might even become indigenous to a country. But all the regular migratory birds are insect-eaters, or nearly so, and spend the summer in one country and the winter in another. They come and depart with considerable regularity as to time, and journey after definite methods. Thus, the spring and autumnal equinoxes herald their arrivals and departures; and, whilst some fly in flocks, others proceed singly. In fine, each species adopts a particular mode of travelling; and year after year, for unreckoned ages, has this coming and going been continued more or less throughout great portions of the globe.

During March, April, and May, an observer on the southern and eastern shores of our islands, or, in fact, anywhere along the routes pursued by birds of passage, may note many interesting facts connected with their times of arrival, and the order and punctuality of their movements (Fig. 2). By far the greater number of the permanently migratory species—by which is meant such as the Swallows—are insectivorous. But not only do they subsist entirely on insects and the like, but each species shows a predilection more or less for particular sorts—a point of much importance when we come to consider the times of arrival and departure of different birds. It will be apparent, therefore, that such as the Swallow tribe, and many warblers, have no choice between starvation and cold on the one hand, and plenty of insect food and a genial climate on the other. Now, if their movements showed no further points of importance than the advancing and retiring within moderate limits, according to their needs, there would be little in their sojournings to create wonder. But this is far from being the case. Some birds perform prodigies in the extent of ground journeyed over, and in the rapidity of their movements. The tiny Ruby-throated Humming-bird of North America proceeds annually from Mexico to Newfoundland, and back; and the majority of our summer songsters cross and re-cross the Mediterranean. The Common Black Swift, so frequently observed circling around church-spires and tall buildings, leaves Northern Africa in March and April, when the climate is genial, and there is apparently no falling off in insect food to necessitate

* Besides these, the Song-thrush, Blackbird, and other sedentary European birds, migrate in large numbers to the islands and southern shores of the Mediterranean during the winter months, and when neither absence of food nor the coldness of the climate can be said to influence them to the extent observed in connection with their compeers of the north.

its departure. Nevertheless, it leaves abruptly, and reaches England and Scotland about the beginning of May. It does not appear to push to the northern limits of its migration with rapidity, possibly on account of the climate of the north being not yet suitable. Portions of the host settle down on the islands and along the northern shores of the Mediterranean; and, whilst the mass is spread over central Europe, the remainder proceed farther northward, until a few reach the Orkney and Shetland Islands. No sooner, however, is the choice of a locality made, than the parental duties are undertaken. The young are hatched by the end of May, and become strong and fly about by the beginning of July, when the broods assemble, and, after a few weeks spent in vigorous evolutions, as if training for the long journey, they suddenly vanish—

> "Like the Borealis race,
> That flit ere you can point their place."

A week afterwards, they may be seen circling around the ruins of ancient Thebes, the walls of Jerusalem, or the minarets of Morocco.

The powers of flight of the Swifts are not surpassed among the feathered tribes. It has been computed that the greatest speed of the Common Black Swift of Europe is about 276 miles an hour, which, if maintained for about six hours, would carry the bird from its summer retreat in England to its winter home in Central Africa. The large Purple Swift of North America is, to all appearances, still stronger on the wing. The Chimney Swallow is said to attain a maximum rapidity of flight equal to about ninety miles an hour; whilst the Passenger Pigeon of North America is believed to travel at the rate of about one thousand miles a day. There can be little doubt that an instinctive impulse comes over the bird of passage at the times of its departure from its winter and summer retreats. This is manifested in various ways. For example, many species, such as the Common House Martin, have been known repeatedly to abandon their second broods in autumn, and leave them to perish miserably, the migratory instinct—or perhaps, rather, the instinct of self-preservation—overcoming parental affection. The writer was witness of a similar occurrence with reference to the Swallows and the Carolina Waxwing, in Canada. The latter migrant is closely allied to the European Waxwing; but instead of being a winter is a summer visitor in New Brunswick, where it arrives about the middle of June, and departs before the end of August. It is, moreover, an insect-feeder to a great extent, and breeds in colonies, so that twenty to thirty nests may be seen within the area of a quarter of a mile. During a rather cold autumn, all the Swallows and the Waxwings suddenly disappeared, and in numerous instances left their unfledged young to die of starvation. Indeed, this yearning to depart seems innate in the constitution of the bird, inasmuch as the young of migrants brought up from the nest, and apart from their parents, display much restlessness at the seasons of departure of their brethren. Now, it will be apparent that, although failure of food in autumn is no doubt the chief factor in the movement at that season, to the same cause cannot be attributed the bird's departure from its winter retreat in the warm climate of Northern Africa in spring, when insect life is equally—if not more—plentifully distributed than during the preceding months. It is consequently this anomaly that constitutes, with the distance travelled, the marvellous characters of the movement in question. The parental duties have been supposed to hasten the spring departure, but there is no evidence of a trustworthy nature to show that birds display any disposition to pair until they have reached the breeding-grounds; it is to be observed, however, that a pronounced change of climate takes place in all regions frequented by the regular migrants of temperate zones. In North Africa, the winter crops are gathered in spring, when the genial climate of the previous months begins to change, and verdure to wither before the hot blasts from the Sahara, which give warning of the approach of the fierce heat of summer. Accordingly, many birds assemble in flocks, and proceed towards the coast; and, possibly, the cooler breezes from the north may beckon them back to the lands from whence in autumn they had been the signals for their departure.

The retreat of the migrant from its summer home is generally more leisurely performed than the advance in spring; but a great deal depends on the food, habits, and constitutional susceptibility of the species. Some birds start much earlier than others, and individuals linger for weeks after the majority of their brethren have departed. The Quail is a great vagrant, especially along the countries of the Mediterranean, where, as soon as the spring produce has been reaped, large flocks of Quails cross the inland sea for Europe, pursuing the same course as when they "came up and covered the camp of the Israelites." Like other birds of passage, they are comfortably plump and fat at the time of their migrations, and, in consequence, are greedily

sought after by the southerners, who wage a destructive warfare, not only on them, but also on all the smaller birds. The far-famed *becca-fico* of the Italians is no other than the pretty little garden warbler, which is considered to be a most delicious morsel. However, when sufficient numbers of the latter cannot be procured, almost every other small bird of passage is substituted, including that prince of songsters, the Nightingale, thousands of whose dead bodies may be seen on the tables of the poulterers.

The sudden disappearance of the Swallow tribe was a subject of wonder even so late as the end of the last century, and various explanations were advanced. By certain naturalists it was asserted that they never left the country, and spent the winter at the bottoms of lakes in a state of torpidity; and even at the present day it is believed a few may hibernate in certain localities; but no authenticated instances have been adduced. The opinion may have originated in the not unusual occurrence when loiterers in autumn are caught by the cold, and become benumbed. The extent of birds' migrations are, doubtless, regulated by their food-supplies. That of species which, like the swallows, capture their prey on the wing, must be dependent to a great extent on winged insects of different species. Now, as insects pass through what has been called a metamorphosis (p. 74), and each group has particular seasons for development, and is limited to a definite period of existence, we can well believe that the Swallow is not likely to continue its sojourn after the particular insect or insects on which it feeds have disappeared. On the other hand, such birds as the warblers, which affect trees, and come in contact with a greater variety of insect life, are more likely to remain longer in their summer retreats. One of the most remarkable European migrants is the Cuckoo (Fig. 3). Like the Swift, it departs early in autumn, when insect life is still plentiful; which may be accounted for by the circumstance just referred to—namely a failure of the particular animal food on which it subsists. The Cuckoo, moreover, furnishes another suggestive instance of a migrant, displaying a restlessness, or the migratory instinct to leave the summer retreat as soon as possible; and considering its short stay and very extraordinary behaviour during its sojourn in Europe, one is lost in wonder to understand why it takes the trouble to come all the way to the bleak north in order to deposit its eggs in other birds' nests, and depart immediately afterwards. The Cuckoo crosses from Africa in March and April. No sooner is the summer home gained than the well-known call announces its arrival, and as soon as the eggs are deposited in the nest of some unsuspecting Hedge Sparrow, Titlark, or Wagtail, then the "sweet messenger of spring" ceases to chaunt, and begins to think of beating a retreat southwards.

Fig. 1.—Passenger Pigeons (*Ectopistes migratoria*).

Altogether, the British visit does not extend over three months, so that if the Cuckoo built a nest and reared its young, there would be very little time to spare. But there is this peculiarity in the mode of laying the eggs: each egg is deposited in another bird's nest, and at intervals of two or three days. Consequently, the young are of considerably different ages

Now, if the parents reared their young, the latter would be of all ages, and the older would be fledged and flying before the youngest could leave the nest, so that under these conditions the arrangement seems extremely well adapted to the habits of the Cuckoos, which, however, are not the only birds that lay their eggs in the nests of other species

The well-known Night Hawks of the Old and New World, and Australia, make also short stays in their summer retreats. In the case of our Night Hawk or Churn Owl, it deposits its eggs on the bare ground, perhaps for the reason that it has not time to build a nest, seeing that, besides its short sojourn, it moves about only at twilight, during which times the journeys to and from Africa, the procuring of food, and the duties connected with the rearing of the offspring, have to be performed Although migratory birds maintain much exactness in their times of arrival and departure, there are frequent

Fig 2—Arrival of Migratory Birds

exceptions to the rule. Sometimes individuals exceed the limits of their annual areas of migration, and wander far away from their accustomed haunts, whilst others are borne on the wings of the wind to distant lands, such as occurs occasionally to migratory birds of North America, a few of which have turned up from time to time in Europe during equinoctial gales. Indeed, of the vast host of birds that cross the Mediterranean sea and English Channel not a few perish on the way, and their bodies are washed ashore, whilst many instances have been recorded of flocks of night-wanderers striking against rocks and light houses.

The most wondrous feat performed by migratory birds is that recorded by Dr. Jenner, the discoverer of vaccination. He captured several Swifts, in Gloucestershire, and marked them by clipping two claws from a foot of each, and then set them at liberty, when individuals so marked were caught at their old nests every year for three successive seasons, and even one was taken with the indelible mark on its claw after the expiration of seven years. Carrier Pigeons also illustrate the same instinct, but not, however, to the extent displayed by the experiments of Jenner. Other instances have also been narrated of the same Swallows having returned annually to their nests of the previous year. It must, however, be understood that the occupants of old nests need not necessarily be the original builders; but supposing that now and then suchlike occurrences take place, as in the case of the Swifts, what a marvellous display of intelligence they exhibit! Here we have a bird, reared in Great Britain, after two long journeys and an absence of seven months in Northern Africa, returning to the nest of the previous year. Even admitting the powers of flight and acute vision possessed by the Swallow tribe, and the probability that the summer home is characterised by certain well-defined landmarks, there still remains the mental effort requisite to treasure up a remembrance of the locality during several months of daily-changing fortunes, not to speak of the work of the two long journeys. It is possible, however, that migratory birds, through long experience and the necessities of their existence, have acquired strong powers of memory in connection with their favourite haunts, seeing that almost every species builds in its own especial situation. The Storks repair to the tall steeple, the Swallows to eaves of houses, and the Thrush builds in the fork of a tree; in fact, each species selects one situation in preference to another.

Fig. 3.—The Cuckoo (*Cuculus canorus*).

No doubt birds are guided to and from their retreats by such landmarks as mountain ranges, coast-lines, and in autumn by the sun. The majority of the migrants of North America follow the Atlantic and Pacific coasts, and many European species cling to the western shore-line, as is shown by the frequent occurrence of individuals alighting on ships; but not a few pursue their journeys at night, and others fly at such high elevations that the physical outlines of continents are not likely to be of much use to them. In the island of Malta, where many European migratory birds delay for a short time in spring and autumn, the writer found that a large number arrived and left at night, and that many came in during adverse winds; others drifted

before the wind, and seemingly with much discomfort; whilst numerous birds of feeble flight appeared much exhausted, and occasionally succumbed to the fatigues of their adventurous journey.

Considering, therefore, the pressing nature of the migratory instinct, and the mishaps which surround the bird from over-fatigue, the elements, and foes, it may be surmised that not a few perish on the way, whilst the strongest are likely to survive.

It appears, moreover, at all events in many species, that the male birds precede the females in spring, and that the broods of the year often accompany the parents in the return journey in autumn. No sooner, however, do they arrive at their summer retreat, than the choice of a mate becomes the first consideration, and the indigenous as well as migratory birds, which had continued mute during the winter months, now burst into the most fervent outbreaks of song, vociferation, and gesture. The exuberant chirpings of the modestly-decked Sparrow, the hoarse croakings of the Crow, and the musical strains of the Nightingale, Thrush, and Skylark, are the overflowings of happy hearts, excited by the allurements of the vernal season, and, doubtless, are frequently meant to charm the female. But many birds sing apparently for an occupation, and are excited by rivalry, as is frequently observed in the case of the Cock Robin, whose joyous notes and ever-welcome form announce his presence nearly as often among the frost and snow of mid-winter as in mid-summer; indeed, he may be heard discoursing sweet music in autumn, during that very dismal atmospheric condition "a London fog."

> "On the nigh-naked tree the Robin piped,
> Disconsolate; and through the dripping haze,
> The dead weight of the dead leaf bore it down."

The extent of the migration of birds varies considerably as to time, as well as the distance travelled. For example, the Common Chimney Swallow commences its return movements to Europe early in March, and continues up to the middle of May, whilst almost every Swift has passed across the Mediterranean by the end of April.

Again, although the Cuckoo appears on the islands and northern shores about the middle of March, it is well on in April before any considerable numbers arrive in the British islands. Indeed, in comparing the dates of arrival of several migrants at Malta and in the north of Scotland, we find that about a month may be allowed between the earliest announcements at these points.

Migrations may be complete, or partial—that is to say, all the individuals of a species may abandon their summer retreats, or the greater number may leave, whilst a few may tarry in diminished numbers throughout the winter. All the Swallow tribe quit Europe throughout the cold months; and the same might be said of the Cuckoo, Night Hawk, and many warblers; whilst some of the latter retire to Southern Europe, and a few of the Wagtails even manage to struggle through our winter by repairing to sheltered situations. The well-known Migratory Thrush of North America (Fig. 4) is a good illustration of a hardy bird, showing a strong disposition to tarry in its summer retreat as long as supplies are procurable. It is, however, compelled to quit Canada and the northern States when the autumn fruits are gone, and the soil has become frozen; but it does not do so until the last reserves have been exhausted, whilst a few sometimes manage to brave the winter by repairing to sheltered situations, and feeding on hips, haws, and other winter berries. A great deal, of course, will depend upon the constitution and power of resisting cold, in which there are great differences among the feathered tribes. Size is no criterion as regards power of endurance, inasmuch as the Golden-crested Wren, the tiniest of European birds, braves the most severe of Scottish winters. Swallows are very susceptible of cold, and, in com-

Fig. 4.—The Migratory Thrush (*Turdus migratorius*).

mon with other sensitive birds, fall victims to sudden accessions of low temperatures, more especially should the latter have been preceded by scanty supplies of food. Indeed, the migratory bird has often severe struggles, as before indicated, which no doubt result in the preservation of the most favoured individuals.

Taking the foregoing phenomena into consideration with reference to the probable origin of birds' migrations, we shall now try to find their explanation in the history of the areas in which the birds themselves sojourn. As far as historical evidence extends, there is little if anything in the past history of continents beyond certain influences exercised by man on the distribution of animals* to account for the character and extent of many of the migratory movements of birds. It is different, however, when recourse is had to the records of the rocks, for in them we find proofs of changes of the surface, and climates very different in character and extent from anything of the kind now existing in the same latitudes. Confining our inquiries to the northern hemisphere in general, and the European and North African areas in particular—or, in other words, to the regions frequented by the migratory birds of Europe—we find certain considerations worthy of notice. But the subject is too voluminous in its details to allow of more than a brief sketch of the results of patient and diligent researches in connection with the animal and vegetable relics, and mineral components of the various strata composing what have been named the Tertiary Formations by geologists. (*Frontispiece.*) Going no further back than the Miocene or Mid-Tertiary period, there is very cogent evidence to show that the climate of Central and Northern Europe, even far into the Arctic Regions, was so mild and genial that animals and plants of equatorial latitudes flourished on land and sea. This period, like all other geological expressions of time, was of vast duration, but towards its close the climate began to get colder, and refrigeration steadily increased during the succeeding or Pliocene period until it culminated in what has been called the Glacial Epoch,† when Northern Europe, Asia, and America were shrouded in an Arctic climate. Finally, the Ice Age gradually passed away, and the temperature assumed its present condition. Again, we know, from equally cogent evidence, that the British islands formed portions of the continent of Europe, both before and after the Glacial Epoch; and that Southern Europe and Northern Africa were also joined together by land; so that the migratory birds, as in North America at the present day, might have journeyed over a continuous land-area from Scotland to the Atlas Mountains. At length, changes of level took place, which eventuated in the present physical features of Europe and Africa. Now, what do these data suggest in connection with the history of the migratory movements of birds? They indicate, *Firstly*, that the summer retreats and breeding-grounds of our migratory birds may have been the permanent homes of their ancestors during the genial climate of the Miocene period. *Secondly*, that as the cold gradually set in, so they retired; at first, just as many of the birds of the Orkney and Shetland Islands now seek our southern shores in mid winter; but as the cold increased, and vast eons passed away, they retreated still further south over continuous areas, even to their present limits. *Thirdly*, as the Glacial Epoch began to decline, so they advanced, and whilst Ireland was gradually separating from Great Britain, and the latter from the Continent, and the Straits of Gibraltar and the great Inland Sea were forming, they still continued their comings and goings, year after year, for unreckoned ages. From this point of view what is called the "instinct" of migration appears to be nothing more than an inherited habit which has become modified to the extent exhibited by our native birds in consequence of their adapting themselves to circumstances; whilst such as the Swallows, and other purely insectivorous birds, have no alternative than to retire when their food-supplies fail them. This hypothesis, moreover, explains the tendency to migrate southwards in many resident birds, and also the general disposition to return to their ancient haunts in spring. Now, although these are supposititious views, they rest on a platform of facts. It is true that extremely few birds of existing species have hitherto been discovered in strata belonging to either the Miocene or Pliocene periods; but relics of several living quadrupeds show that they sojourned in the British islands before the Ice Age. So that, if they were enabled to survive by migrating southwards, how much easier would it have been for the feathered denizens to have done the same!

This attempt to explain the phenomena of the migratory movements of birds by having recourse to the records of former conditions of land and climate in the regions they now frequent, is a striking illustration of the value of a knowledge of the past changes of the earth's surface in elucidating phenomena occurring around us; and whether or not they solve the difficulties of the case, no one can fairly dispute their significance.

* In connection with birds, the Cliff Swallow of North America is said to have extended the easterly limit of its migrations from the Rocky Mountains to the east coast within the last century.

† The reader is referred to "A Highland Glen," p. 33, for an account of this Glacial Epoch.

# THE MAINSPRING OF THE CELESTIAL MECHANISM.

By Richard A. Proctor.

COPERNICUS had shown that the movements of the planets can be much more simply explained by supposing that the sun is the centre round which they and the earth all travel. But his theory was by no means so satisfactory as many who have written on this subject seem to imagine. It is supposed that his theory at once swept away all the epicycles and eccentrics of the older or Ptolemaic astronomy. If this had been so, the theory would probably even in his own day have found ready acceptance. But this was far from being the case. I need not here consider the various details which the Copernican system failed to explain. Let it suffice that they were many. Starting with the idea that all the celestial movements were of necessity circular and uniform, and that whatever peculiarities of motion appeared were due only to peculiarities in the combination of various uniform circular movements, Copernicus and his first disciples naturally failed to explain movements which we now know to take place in non-circular paths, and with variations irreconcilable with any system of subordinate cyclic motions. In fact, Copernicus was able to throw on one side the principal set only of subordinate cycles; all the rest were as necessary to his system as to that of Ptolemy. And the difficulties which exact observation had introduced—difficulties which before his time had rendered the Ptolemaic system unsatisfactory to mathematicians—in reality affected his system quite as much as the Ptolemaic, and must in the long run have compelled astronomers to reject it as advanced by Copernicus himself.

When we add to this consideration the circumstance that Tycho Brahé—one of the greatest observational astronomers the world has known—rejected the Copernican theory, we must admit that it would probably before long have been forgotten, like some older attempts to set the sun at the centre of the solar system, had not an entirely new series of arguments been adduced in its favour, or rather in favour of the theory that the sun and not the earth is the centre of the solar system.

Copernicus, like all astronomers who had preceded him, had tried to find out what the actual motions of the planets are. The astronomers who now took up the subject tried to find out how these motions are brought about. He had endeavoured to ascertain what is the mechanism of the heavens, as one studying a clock or machine might endeavour to find out how the various wheels, pinions, teeth, and so forth, are related together. Astronomers now began to look for the mainspring of this mechanism, as one who had noted the connection of the various parts of a clock or machine might try to find out by what power these parts were set in motion.

The inquiry from this time went on upon two parallel lines. If Copernicus had indicated the exact nature of the planet's motions, men could have set to work at once to determine how these motions might be produced. As he had not done this, it was necessary now, while inquiring into the probable cause or causes of the celestial motions, to ascertain more precisely what these motions are. Kepler undertook this part of the work. He tried a number of combinations of circular and uniform motions, and compared the observed motions of the planets as seen from the earth, with those which his calculations showed would be the result of such combinations. Tycho Brahé had erected an observatory at Uraniberg with the express object of collecting observations to overthrow the Copernican theory. These he left in his will to Kepler, enjoining only that they should not be employed to establish this theory. Kepler, however, disregarded this injunction. Selecting a series of observations of Mars from among the mass collected by Tycho Brahé, he compared them one after another with his calculations on various epicyclic theories. Mars was specially well suited for Kepler's purpose. It is our nearest neighbour among the superior planets (or planets farther from the sun); and it moves in a very eccentric orbit, the greatest and least distances of Mars from the sun being, respectively, 153,000,000 and 127,000,000 miles. On both accounts it was easier to test various theories of this planet's motion, than it would have been in the case of any other member of the sun's family.

One theory after another was tried by Kepler and rejected. After many years of such labours, having exhausted the combinations of circular and uniform motion, he tried the ellipse for the form of the planet's path, and several theories of varying motions in such a path. At last, he discovered a law of motion in an elliptic path which fitted in

exactly with all Tycho's observations of the planet Mars. An ellipse, as A B A′ B′ (Fig. 1), besides having, like the circle, a centre (C) such that every chord through C is divided in half at C, has also two important points, S and H, called *foci*, so situated that the sum of two lines (S P, P H) to any point (P) on the curve is equal to the longer axis A C A′ on which also these points S and H lie, at equal distances from C. From this property is derived a familiar (though not very convenient) method of tracing an ellipse: for if at S and H there are two pins, and a fine inextensible string (S P H) be passed round these pins, a pencil point so moved as to keep the string stretched to its full length, as shown at P and P′, will trace out an ellipse. Now Kepler found—first, that Mars describes an ellipse as A B A′ B′ about the sun situated at one focus as S; and, secondly, that the rate of the planet's motion varies in such sort that equal surfaces are swept over in equal times by an imaginary line from the sun to the planet. The second law may be thus illustrated: suppose that P P′ is a part of the orbit of Mars traversed in the same time as the part $p\ p'$; then if the straight lines S P, S P′, S $p'$, S $p$ are drawn, the surface P S P′ is equal to the surface $p$ S $p'$. This is true whether P P′ and $p\ p'$ be large or small.

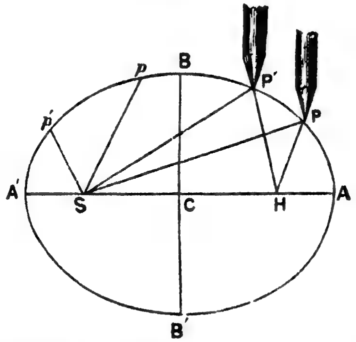


Fig. 1.—Illustrating the Nature of the Ellipse, and of a Planet's Motion in this Curve

Testing these laws by the observed motions of the other planets, Kepler found that both laws are strictly fulfilled. The earth's motion around the sun, he found, fulfils also these laws. He therefore was able to enunciate confidently his two first laws.

*Kepler's First Law.*—Each planet moves in an ellipse around the sun, which is situated in one focus of that ellipse.

*Kepler's Second Law.*—A straight line extending from the sun to the centre of a planet sweeps over equal surfaces in equal times.

These laws, as advanced by Kepler, were both what is called empirical. They corresponded with observed facts; but there was no reason known to him why the planets should obey these laws. Nay, it was not absolutely proved even that these are the true laws. Kepler had no means of assuring himself of the relative distances of Mars at different observations, and it was *possible* (so far as he knew) that the planet was sometimes nearer, sometimes farther away than it should be if strictly fulfilling this law. A bird might fly in a uniformly curved path so as to seem to follow the moon's track across the sky, or he might fly on an irregular real path, now approaching the observer, anon receding to a great distance, yet always so moving as to *seem* to trace out the same path as in the former case, and at the same rate. All Kepler knew for certain was that if the planets' real paths were such as his two laws indicated, the apparent course of each planet would correspond with observation. But it was so utterly improbable that this exact agreement should hold, unless the two laws were the true laws of planetary motion, that Kepler was able very confidently to announce them as such.

And now he went a step farther. The two laws above stated apply severally to each planet. But he noticed signs of a certain harmony among the movements of all the planets—that is, of the planets as forming a family.

He selected, after sundry trials of other relations which need not here be considered, the periods in which the planets severally complete their circuits and the relative mean distances (C A or C A′ of Fig. 1) at which they severally travel around the sun. Let us set these down in order as known to Kepler, putting the earth's distance as unity, and also putting the earth's period—one year—as unity. The reader who does not happen to know the actual relation between the distances and the periods as thus shown, will find it a useful exercise before reading what follows, to see whether he can perceive the law which harmonises these sets of numbers:—

| | Mercury | Venus | The Earth. | Mars. | Jupiter | Saturn |
|---|---|---|---|---|---|---|
| Distances of the Planets (earth's distance, 1) | 0·387 | 0·723 | 1·000 | 1·524 | 5·203 | 9·539 |
| Periods of the Planets (earth's period, 1) .. | 0·241 | 0·615 | 1·000 | 1·881 | 11·862 | 29·457 |

We see at a glance that the periods vary at a greater rate (to use a somewhat inexact expression) than the distances. But in reality we need not consider the entire sets of numbers at first, seeing that if there is a law it will probably show

itself in the case of any pair of planets we choose to consider. Take, for instance, the earth and Jupiter. Having expressed both the distance and the period of the earth by unity, we have, in fact, only the two numbers 5·203 and 11·862 to examine. The law of harmony, if it exists at all, ought to show itself in these two numbers. As Kepler very soon fell upon the notion that harmony exists among the "powers" of such numbers, he ought, one would suppose, to have at once detected the law; for 11·862 is greater than the first power of 5·203 (that is, than this number itself) and less than the second power or the square of 5·203 (27·071). The natural course, therefore, would now be to try a power half-way between the 1st and the 2nd, or the power $\frac{3}{2}$. The way to do this is to take the cube or third power of 5·203, getting 140·851454, and then to take the square root of this number, 11·868. This is very near to 11·862, and would have been nearer if, instead of 5·203, I had taken the true distance, 5·202798, which I did not do because of the long numbers which would have come in. Here, then, is a relation between the distances and periods of the earth and Jupiter. If only the same relation is found to exist between the distances and periods of the other planets compared in the same way with the earth's, we shall know that this is a law harmonising the entire system of planets. But this is found to be the case. If any one of the numbers in the top row, or row of distances, is cubed, and the square root of the resulting number taken, this square root will be found to be identical with the corresponding number in the lower row, or row of periods. Or otherwise, if two numbers in the same vertical column be taken, it will be found that the cube of the upper is equal to the square of the lower.

This is the simplest way in which the relation called Kepler's third law can be expressed and illustrated; and I have always found it convenient to present the law in this way. The more usual way, which, of course, really implies precisely the same law, is as follows: Take any two planets, as the earth and Jupiter, and write down their distances from the sun (in miles, say), and their periods (in days, say) thus:—

| | Earth's. | Jupiter's. |
|---|---|---|
| Distances .............. | 91,430,000 | 475,692,000 |
| Periods ................. | 365·2564 | 4332·5848 |

then, if the two upper numbers be cubed, and the two lower numbers squared, the four numbers thus obtained will form a proportion, thus:—As the cube of 91,430,000 is to the cube of 475,692,000, so is the square of 365·2564 to the square of 4332·5848, a result which the reader will find true on trial.

Kepler somehow failed at first to see that the law was fulfilled, even after it had occurred to him. Two months and a half elapsed, through some error in his calculations, before he recognised the truth of the law. It may be thus expressed:—

*Kepler's Third Law.*—The squares of the periodic times of the planets vary as the cubes of their mean distances.*

These three are the laws according to which the planets, including our own earth, actually move around the sun. Each planet traces out its proper ellipse, with a velocity varying according to the second law, and the movements of each planet are so related to the size of its elliptic orbit, as to bring all the members of the family under the third law. When Jupiter's moons were discovered, it was found that they also move in accordance with these laws. So far, indeed, as the third law is concerned, we cannot compare the path and period of one of these moons with the path and period of a planet around the sun; but the path and period of one of Jupiter's moons, compared with the path and period of another, accord with the third of Kepler's laws.

Here, then, if we only know the laws of motion, we have a means of finding out the mainspring of the celestial mechanism. We know *how* the planets move. If we can only determine under what forces or impulses bodies *would* so move, we must be guided presently to the recognition of the centres where such forces reside.

While Kepler had been thus determining how the planets move, another great reasoner---Galileo—had been inquiring into the laws according to which bodies move under the action of forces of different kinds.

It seems strange now to consider how vague (and incorrect where not vague) were men's notions three centuries ago, about the laws of motion. Thus, even Galileo for a long time did not arrive at the simple conception that if a body is at rest it will

* It will readily be found that, as a result of the third law, the mean velocities of the planets vary inversely as the square roots of their mean distances from the sun. It has occasionally happened that this law, which is a direct consequence of Kepler's third law, or indeed, practically equivalent to that law, has been re discovered independently by students of astronomy, and has been regarded with some complacency as a new law. whose recognition should immortalise the discoverer.

remain at rest, and if it is in motion it will continue to move in one direction with unchanging velocity, so long as no force acts upon it. He thought the only kind of motion which would continue unchangingly was uniform motion in a circle. Presently he noticed, however, that in every case of such motion, whether of a fluid whirling round inside a smooth circular vessel, or of a ball swinging in a circle, there is always some cause at work to deflect the moving matter or body into its circular path. The moment this cause ceases to act, as when the inclosing sides of a vessel containing a revolving fluid burst, or when the string by which a ball is swung round, breaks, the matter or body which had been moving in a circle flies off (or at any rate begins to fly off) in a straight line—viz., in the direction of a tangent to its former course at the point where the matter or body was released. Further consideration soon led him to recognise and enunciate the

*First Law of Motion.*—A body if at rest will remain at rest, or if in motion will move in a straight line with uniform velocity, unless it is acted on by some extraneous force.

Galileo next inquired whether a force acting in any direction upon a moving body produces the same effect as on a body at rest. Many experiments seem at a first view to suggest that this is not the case. If, for instance, a ball moving swiftly along in a given direction is struck by a bat moving in the same direction with a given greater velocity, the additional velocity communicated to the ball is less than the velocity communicated to a ball at rest by a bat moving in the same manner. The moving ball is, so to speak, yielding before the advancing bat. And here precisely we perceive why such an experiment does not prove that a force exerts more or less force on a body at rest than on a body in motion; for we see that the moving ball is not acted upon by so powerful a stroke as the ball at rest, and this alone may be the reason why a smaller addition of velocity is imparted to it. A number of other experiments, free from objection, show that a force produces precisely the same effect on a moving body as on a body at rest. These experiments are familiar, and belong rather to general mechanics than to the mechanism of the heavens. It is, however, important to notice that in one series of experiments—those relating to falling bodies and to projectiles, Galileo dealt with terrestrial gravity, and thoroughly investigated the nature of its action. It is altogether a mistake to suppose that Newton was the first to recognise the nature of gravity in this respect—that is, in its action on projectiles and falling bodies. We owe, then, to Galileo, the

*Second Law of Motion.*—The effect produced by a force acting upon any body is the same, both in direction and in amount, whether the body is at rest or in motion.

Lastly, a greater mathematician than either Kepler or Galileo established yet another general law of motion. The two laws just stated relate to the action of forces on a particular body. It is necessary to have the means of comparing together the forces affecting different bodies—bodies containing unequal quantities of matter. Newton showed by a number of experiments, carefully reasoned upon, that if a given force communicates to a certain mass of matter a certain velocity in a given time, a force which shall in the same time communicate an equal velocity to another mass larger or smaller than the former mass must be in the same degree greater or less than the former force. In other words, two forces ($f$ and F) which in a given time communicate equal velocities to two masses ($m$ and M), must be related to each other according to the following proportion:—As the force $f$ is to the force F, so is the mass $m$ to the mass M.

The third law has been variously expressed. Some writers simply state it thus: "Action and reaction are equal and opposite." This is the way in which Newton expressed the third law in his "Principia," but in reality he so expressed the second law as partly to include what is now considered the third law, and it is only when this is done that the above method of stating the law is sufficient. The best way, perhaps, of stating the law here will be as follows:—

*Third Law of Motion.*—When a force acts on a body, the total quantity of motion communicated is proportional to the force so acting.

Now let it be noted that while these three laws enable us to determine what will be the effect of such and such forces acting on bodies of such and such mass, and moving in such and such a manner, they also enable us to learn from the observed changes in the motions of moving bodies the nature of the forces which have acted upon those bodies. It was in fact by applying the laws in this way that Newton ascertained where the forces reside which guide the motions of the heavenly bodies.

In the first place, since the planets do not move in straight lines, but are constantly changing the direction of their motions, we see from the first law of motion that some force must be constantly

acting upon them. Thus, let A B C be part of the curved path of a planet around the sun S, and for the moment regard the path as circular. When the planet is at B, it is travelling for the moment in the direction B T, a line touching the circle A B C at B, and it would continue to travel in that straight line unless a force acted upon it. By the second law, again, we can tell the direction in which the force has acted which has made the planet leave the tangent B T. The planet moves in the path B C, deflected from B T towards the side on which S lies; and therefore the force deflecting the body must have been directed towards that side of B T. Observe, I do not say towards the point S itself, *as yet*.

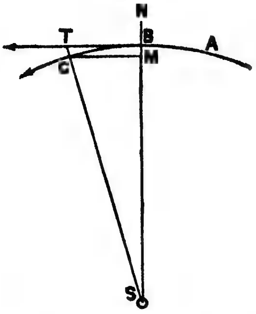

**Fig. 2.—Illustrating the Direction of the Force acting upon a Planet.**

And here, in passing, let me correct a very common error, arising from the inexact way in which these matters are too often dealt with. It is quite commonly supposed that a planet moving in such a path as A B C is under the influence of two balancing forces, one towards S, called the *centripetal force*, and the other from S, called the *centrifugal force*. If we consider the motion of a planet over any part of its path, without any supposed knowledge of the force acting on the planet, but judging only of the direction in which such force acts by the way in which the planet behaves, we see at once that the force must be towards the centre. The planet B moving at the moment towards T, is found, after a short interval, at C, instead of T, where, if not acted on by any force, it would have been. It has then been deflected in direction T C towards the side of B T on which S lies. There is, then, no centrifugal force acting on the planet, but always a force towards S.* We need, in fact, consider only this: that if a body at B, moving so that it would reach T in a certain interval of time, receives an extraneous impulse whose action causes the body to be found at C at the end of this interval, then, drawing C M parallel to T B, B M represents this impulse in direction and magnitude on the same scale on which B T would represent an impulse competent to give the body its motion in direction B T. We know from the observed course of the body that no force which would have to be represented by such a line as B N has acted at all upon it. In other words, from the observed motion of a planet at every point of its orbit, we know that no centrifugal force has acted on the planet.

* The expression "centrifugal force" used by Newton correctly according to his own explanation of the word force—which made *inertia* a force—would only be correctly applied, according to the modern use of the word force, if Galileo's first notion, that bodies not acted on by any force would move uniformly in a circle, were correct. So soon as we recognise that a body not acted on by a force will move uniformly in a straight line, we see that a body which leaves the straight course must be acted on by a force directed towards that side on which the body is deflected from its former straight course.

Next, Newton showed that Kepler's second law indicates the sun as the centre of force deflecting the planets constantly from the tangent to their paths. To prove this, he was obliged to adopt the device of imagining the continuous action of the sun changed into a succession of impulses following each other in very rapid succession. Suppose a planet at A (Fig. 3) is travelling at the moment in the direction A T, and suddenly receives an impulse from the sun S which would bring the planet to M in the same time in which, if undisturbed, it would travel to T. Then we know that A B, the diagonal of a parallelogram having sides A T and A M, will be the actual course of the planet. But the triangle A B S has a surface equal to that of the triangle A T S, because they are of equal height on the base A S. So that the impulse exerted towards S has not affected the area swept out by the planet around S. In the next equal small interval of time, again, the planet would move on to *t*, such that B *t* is equal to A B, thus sweeping out the surface B S *t* equal to B S A. But if suddenly pulled towards S in such a way that it would traverse a distance B *m*, in the same time which would carry it undisturbed to *t*, its actual course will be B C, the diagonal of the parallelogram having *t* B and B *m* as sides. And we see that the triangle B S C is equal to the triangle B S *t*; or *again*, the area swept out around S is unaffected by the impulse towards S. It is obvious that if the impulse were not towards S the area would be affected. If M lay on the same side of A S as T, T B, parallel to A M, would not be parallel to A S, but would give a triangle (A B S)

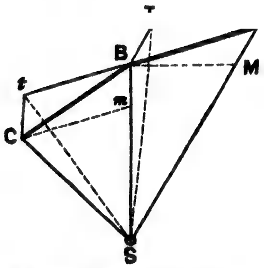

**Fig. 3.—Showing how the Sun is proved to be the Centre of attractive Force by which the Planets are governed.**

greater than A T S; and the reverse if M was on the other side of A S. Since, then, we observe that each planet constantly sweeps out equal areas around the sun, we know that the force acting on the planet must be constantly directed towards the sun. Nor is the validity of the reasoning at all affected by substituting for the constant action of the sun a succession of very swiftly-succeeding small impulses. For just as a curved line may be represented by a great number of very small straight lines as closely as we please, and theoretically so closely that no faculties we possess would enable us to distinguish the line thus made up from a true curve, so it is clear that a multitude of swiftly-succeeding small impulses will produce effects so closely corresponding to those of an absolutely continuous force, that no faculties we possess would enable us to distinguish one set of effects from the other.

Having thus shown that the planets must be under the action of a force residing in the sun, and the moons of a planet under the action of a force residing in that planet, Newton next inquired according to what law such a force must act to explain the actual shape of the paths followed by the planets (as shown by Kepler's first law), and also to explain the relation indicated in Kepler's third law.

At first, however, he contented himself at this stage—not fully perceiving yet how great a discovery lay before him—with showing that if the planets' paths be regarded as circles described at the planets' mean distances, then, if the sun's attractive force diminishes as the square of the distance, the third law of Kepler would be fulfilled. By a force diminishing as the square of the distance, is meant a force which, if represented by F at a certain distance, is reduced to one-fourth of F at twice this distance, to one-ninth of F at three times this distance, and so on; or, more generally, if represented by F and $f$ at distances D and $d$, then F is to $f$ as the square of $d$ is to the square of D. What Newton showed at this stage of the inquiry was, that if the sun exerts a force varying in this way with distance, then a family of planets travelling in circles around him must have rates of motion so diminishing with distance that the periods and distances are related in the manner indicated in the third law of Kepler.

It is possible that these inquiries, and the further much more difficult inquiry, whether a planet not moving in a circle round the sun so attracting, would move in an ellipse, might have remained matters of interest only to a few mathematicians but for the momentous discovery now made by Newton. Halley, Wren, and Hooke had accompanied Newton (perhaps even anticipated him, though this is not certainly known) thus far. Halley and Wren had also tried to prove that a planet would travel in an ellipse round the sun if his attraction diminishes inversely as the square of the distance, but they had both failed. Hooke said he had solved this problem, but would keep back his solution till others, failing, acknowledged the difficulty of the problem; but doubtless Hooke had really failed. Newton solved the problem, but laid aside the solution till Halley, by opening the question, recalled his attention to the subject.

But now it so chanced that Newton was led to inquire whether the familiar force of gravity which acts on bodies at all attainable heights above the earth's surface, may not extend to the moon, and be the force which guides her in her orbit round the earth. Supposing this force to reside at the earth's centre; then a mass on the surface is about 4,000 miles from the centre of force; while the moon is about sixty times as far from that centre; so that the force, reduced as the square of the distance is increased, becomes at the moon about 1-3600th part of gravity at the earth's surface. Now, the actual force exerted by the earth on the moon is readily compared with the familiar force of gravitation by noting how much per second (or in any very short time) the moon is pulled towards the earth's centre. The circumference of the moon's orbit is 1,296,000 miles; and in one second she moves half a mile. If B T, in Fig. 2, represent half a mile, and B S the moon's distance from the earth, or about 240,000 miles, it is easily calculated that T S is about 1-230th of a foot longer than B S; T C, then, the amount by which the moon has been drawn earthwards in a second, is about 1-230th of a foot. This, increased 3,600-fold, is about 16 feet—the distance which a body at the earth's surface, if unsupported, falls in a second. Unfortunately, Newton employed incorrect measures of the earth—the same measures which led to the difference between the nautical mile and the common mile. The length of 1-360th part of the earth's circumference was supposed to be 60 miles instead of about 69 miles. Thus, instead of obtaining a result such as I have just indicated, which would at once have confirmed his idea that terrestrial gravity controls the moon's motions, he found the moon's fall towards the earth per second to be about 1-260th of a foot only. He

at once gave up the idea: until, nineteen years later, hearing of Picard's new measurement of the earth, he re-examined the question, and found that the moon's fall earthwards per second is just what it would be if caused by the earth's attraction diminished, as compared with gravity at her surface, inversely as the square of the distance. It is said (though I fancy there can be no truth in the story) that as Newton found the figures tending to the desired end, he became so agitated that he was obliged to ask a friend to complete the calculations. A child could have done this part of the work, and Newton was not the man to be reduced to childishness, even for a moment, at this time (1684), when he was in the prime of his wonderful powers.

But now the secret of the mechanism of the heavens was disclosed. If the moon is guided by the earth's attraction in such a way as to show that this attraction diminishes as the square of the distance increases, and if, as he had already shown, the moons of Jupiter and Saturn, as well as the planets in their courses round the sun, move in such sort as to indicate that *their* respective centres exert attractive forces diminishing as the square of the distance increases, it is natural to infer that this law of attraction really prevails among all the members of the solar system. As the earth controls the moon, so Jupiter and Saturn control their moons, and so the sun controls the earth and the other planets. Thus the attractive power presented itself as a property common to all these masses of matter, and therefore, probably, was to be regarded as a property of matter itself, insomuch that it resides in bodies which fall to the earth as well as in the earth; in the moons of the earth, Jupiter, and Saturn, as well as in those planets; in the stars as well as in the sun. Moreover, if the true law of its diminution with distance was that of the inverse squares, then, though the attraction of any portion of matter would be enormously reduced at any great distance, it would never be reduced to evanescence, and thus every portion of matter, large or small, exerts an attractive influence on other matter even to the remotest depths of space.

Several points had at once to be dealt with, however, before this general theory of the mechanism of the heavens could be regarded as established.

First, Newton had to show that if the earth's attractive force resides not at her centre, but in every portion of her mass, the attraction on bodies near to her, or far off from her, would be the same as though the entire force resided at the centre. This he was readily able to demonstrate, though not by reasoning which could be presented here. The proposition is, indeed, not *str ctly* true. It would only be so if the earth were a perfect sphere. But it is near enough to the truth to accord with observed phenomena. Indeed, the fact that a somewhat flattened globe like the earth does not attract, and is not attracted, precisely as though all its mass were gathered at its centre, leads to one of the most striking proofs of the theory of gravitation, by explaining the slow reeling or gyratory motion of the earth in a period of nearly 25,900 years, which causes what is known as the "precession of the equinoxes." The sun, planets, moons, &c., being all either perfect spheres, or very nearly so, attract and are attracted either exactly as though their mass were collected at their centres, or so nearly so that the difference does not appreciably affect the resulting motions.

Next, Newton had to show that the elliptic paths traversed by the planets accord with the law of attraction, and moreover that Kepler's third law, true for circular paths, would be true also for elliptic paths. This also he accomplished; but again the reasoning employed is not such as could here be presented. A problem which had altogether foiled Wren, Halley, and Hooke, and which even Newton was not able to solve in a simple way, cannot, of course, be so simplified as to be presented without details such as mathematicians only could understand.

Lastly came the most complex part of the demonstration—a portion of the work which even Newton could only begin, and which even in our own time astronomers have not completed. If every portion of matter attracts every other, it necessarily follows that although any given planet would travel in an ellipse around the common centre of gravity of its own orb and the sun's if no other bodies existed in space, yet as every one of the other planets exerts its attractive influence on this one, its motions must be in some degree affected. It must be drawn now a little on one side now a little on the other side of the path it would otherwise have followed; it must be now a little hastened and anon a little retarded in its progress. So the moon in her circuit around the earth must be perturbed by the planets, and in still greater degree by the sun; and so with the moons of Saturn and Jupiter. What had still to be shown, then, was that the motions of the planets, of the moon, and of the other satellites, are really affected in this way. Newton showed that the chief peculiarities of the moon's motion, which before his

time had remained altogether unexplained, though noted, were caused by the sun's perturbing influence on the moon as she circuits around the earth. Since his time, the moon's motions have been more thoroughly dealt with; the perturbations of the planetary motions have been explained; perturbations detected by theory have been observationally recognised; and lastly, as the crowning triumph of the theory that gravitation is the mainspring of the celestial mechanism, observed perturbations not explicable by the action of known members of the solar system have been made to reveal the position of a before unknown planet.

To sum up: Copernicus having simplified the theory of the solar system by setting the sun at the centre, Kepler examining the observed motions of the planets, discovered his three laws;—that the planets move in ellipses round the sun, which is in a focus of each ellipse; that they sweep out equal areas in equal times round the sun; and that the cubes of their mean distances are proportional to the squares of their periods of revolution. In the meantime, Galileo had discovered the two first laws of motion. Of these, the first showed that since the planets do not travel in straight lines, they must be under the action of some force or forces; while the second law showed that since the planets are deflected constantly towards the centre round which they travel, they must be under the action of a centripetal force. Newton showed that the true centre of such motion must be the point round which equal areas are swept out by the moving body; the sun, therefore, is the centre of force governing the planetary motions, the earth the centre governing the moon's motions, Jupiter and Saturn the centres respectively governing their moons' motions. He showed, also, that Kepler's third law indicates that the forces exerted from these centres on the bodies moving round them diminish as the squares of the distances increase. Then he was led to inquire whether the force thus exerted by the earth on the moon may not be the very same force which causes the fall of unsupported bodies at her surface. Having found that this is the case, he recognised as the mainspring of the celestial mechanism an attractive power residing in matter of whatever kind; and after dealing carefully with the chief remaining details of the problem, he enunciated

*The Law of Universal Attraction.*—Every particle of matter attracts every other particle with a force varying directly as the product of the numbers representing their masses, and inversely as the square of the number representing the distance between them.

# OPTICAL ILLUSIONS.

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It is admitted by everybody that, of all proofs that can be adduced in support of facts, none are so convincing to a man as the evidence of his own senses. That which he has seen or heard or handled becomes fixed upon his mind as a reality far more vividly than it could be by any other kind of evidence. It is a proverbial expression that "seeing is believing," and the evidence of the ear, of the sense of touch, and in certain cases of the senses of taste and of smell, are hardly less convincing. All this shows the marvellous perfection of the various organs of sense through the instrumentality of which the mind is made acquainted with the outer world.

The eye, considered as an optical instrument, is of extraordinary perfection and adaptability to the purposes for which it is employed; it combines in itself the instruments known as the telescope, the microscope, and the camera obscura, and it has in addition the property of automatically adjusting itself to the continually varying distances at which objects are presented in succession before it; in other words, the focussing of the eye to insure clear vision of objects at different distances is, except in certain special cases, an almost involuntary act. If we look at a landscape through a window, it is perfectly easy to obtain in succession a clear view of the distant horizon or of the window-bars which are close to the eye; and, apart from the exercise of the will or inclination to look from the one to the other, the mind is not cognisant of any effort by which the focus of the eye is adjusted for the longer or the shorter distance. But just as it is necessary for a photographer to alter the position of his lens to obtain upon his sensitised plate a clear image of objects placed at different distances from his camera, so it is necessary for an adjustment to be effected within the eye when it is

directed to objects nearer or farther off. The human eye, a vertical section of which is shown in Fig. 1, is in fact a little camera which, by means of lenses and optical contrivances (identical in principle with, but far more perfect than, those employed in a photographic instrument) forms upon a sensitive film an image of objects to which it may be directed. This sensitive film (corresponding to the prepared collodion of the photographer) consists of a membrane at the back of the eyeball, traversed by a system of nerve-filaments of extraordinary delicacy and sensitiveness, so interlaced as to form a network, which is in consequence called the *retina.* Upon this network of nervous matter is thrown by means of the lens a minute inverted image of whatever objects the eye is directed to; and the

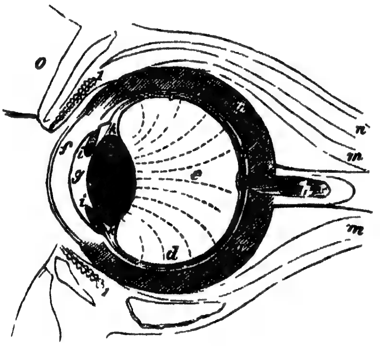


**Fig. 1.—Section of the Human Eye.**

(*a*) Sclerotic. (*b*) Choroid Membrane or Uvea; (*c*) Retina; (*d*) Hyaloid Membrane; (*e*) Vitreous Humour; (*f*) Cornea; (*g*) Aqueous Humour; (*h*) Optic Nerve; (*i*) Iris; (*k*) Crystalline Lens; (*m* and *n*) Muscles by which the Eye is moved; (*o*) Eyelid.

phenomenon of sight may be defined as the reading of the telegraphic message which the retina transmits through the optic nerve to the brain descriptive of the image that is falling upon it. But, while this message is, in a healthy state of the eye, always correctly transmitted by the retina, and is almost always correctly interpreted by the brain, the proverbial statement that "seeing is believing" has, like every other rule, its exceptions; and it is the object of this paper to bring before its readers a few of the most striking of those exceptions, which are known as "Optical Illusions."

Every boy is familiar with the experiment of making a ring of fire in the air by swinging round the red-hot end of a burning stick. The luminous ring so formed is obviously an illusion, for it is clear that the light from the incandescent point can come from only one position in its path at any one time. It cannot be at the same instant at both ends of the diameter of the circle, and yet the eye can detect no break in the continuity of its path. This experiment is a simple and characteristic illustration of a large class of optical illusions, which result from a very necessary property of vision, which is called the "persistence of visual impressions on the retina"—that is to say, an object placed before the eye and suddenly removed, is seen for a certain appreciable time after its removal. This persistence of the image on the retina—or what is for practical purposes the same thing, the impression on the brain of a persistent image—facilitates the exercise of sight; it gives time to the mind to take in the message, and to interpret its meaning. Were it not for this property, the eye in the act of reading would be compelled to rest for a longer period on each word to enable the mind to understand it, and by the necessary and involuntary act of winking the eye would be plunged into darkness at every few seconds. The time that this impression lasts has been variously estimated at from one sixth to one eleventh part of a second, but it is very generally regarded as about one-eighth of a second. The explanation, therefore, of the luminous ring formed by a lighted stick is that the impression made by it at any one point of its course remains on the retina until it again reaches that point. For the same reason, a vibrating string, such as that of a harp, or other musical instrument, appears as a flat transparent film filling up the space included between the two extremes of its amplitude of vibration. Similarly a red-hot cannon-ball fired at night appears like a long line of light or as a luminous stick travelling through the air in the direction of its length. Were it not for this phenomenon of vision, some of the chief attractions of fireworks would be lost altogether; the rocket would have no fiery train, the catherine-wheel would exhibit but a shower of sparks, and the larger revolving "set pieces" would be but slightly more attractive.

Upon this principle is founded a large class of optical toys, of which the following may be mentioned as examples. The Zoetrope or "Wheel of Life" consists of a shallow cylinder of zinc or cardboard, open at the top, and centred on a vertical axis, so that it can be rapidly rotated. The circumference of this cylinder is pierced at equal distances by a number of vertical slits through which the inner circumference may be seen when the instrument is in rotation. On the inside, and below the slits, is placed a strip of paper, having drawn upon its surface a series of pictures representing the different attitudes successively assumed by an object in completing the cycle of a given movement. Thus

a juggler may be depicted, in the act of throwing up and catching a ball, by say twelve drawings, of which the first six respectively represent the ball at various positions in its upward flight, and the

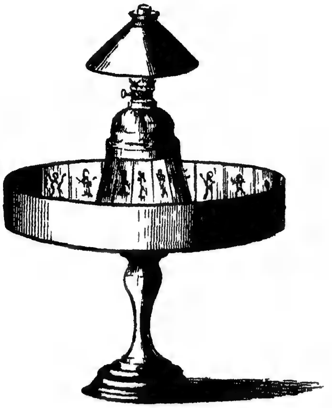

Fig. 2.—The Praxinoscope

next six at as many positions passed in its descent, the successive positions of the arms and body of the figure being similarly portrayed. When this series of diagrams is rotated in the zoetrope, and looked at through the rapidly moving slits, the effect is that the pictures appear to be suddenly endowed with life, and if the phases be correctly drawn, the illusion is complete. A very ingenious modification of the zoetrope, brought out some years ago, is represented in Fig. 2. In this instrument, to which the name Praxinoscope has been given, the vertical slits are dispensed with, the figures being seen in succession in a set of small mirrors arranged round the frustrum of a cone placed at the centre of and revolving with the drum carrying the figures. This is a great improvement upon the zoetrope; for, on account of the substitution of mirrors for rapidly-passing slits, a much smaller percentage of light is lost, and the use of the instrument is unaccompanied by the unpleasant and fatiguing effect upon the eyes, of which so many people complain with respect to the older form. A candle or a small lamp is placed above the conical drum carrying the mirrors, for the purpose of illuminating the figures.

Another optical toy depending upon the same principle is the Thaumatrope, shown in Fig. 3, which consists of a card, which can be rotated about its middle line by means of strings attached to its edge; if upon one side be painted the representation of an object, such as a horse, and on the other side be depicted a rider, when the disc is made to rotate, the man and the horse will be seen at the same time, and, if they be properly placed with respect to the axis of rotation, the man will appear to

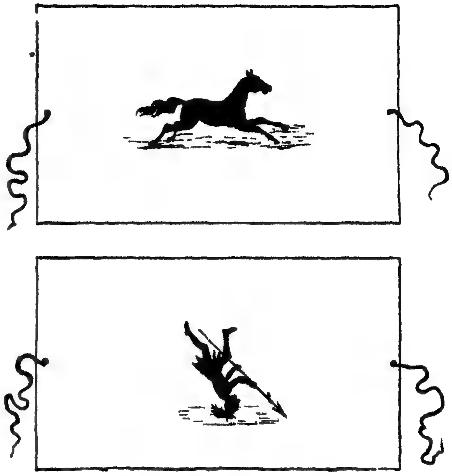

Fig. 3.—The Thaumatrope.

be riding on the horse. The Phenakistoscope, Anorthoscope, and many others are also modifications of the instruments which have been described.

One of the most beautiful applications of the principle upon which the simple experiment of making "a ring of fire" is founded, is the method by which M. Lissajous analysed the harmonic combinations of two musical notes, by the curve traced upon a screen by a spot of light reflected by mirrors attached to the tuning-forks, which vibrated in planes at right angles to one another. The curves so produced are known as "*Lissajous' figures*," and are of great beauty, which is due entirely to the optical illusion which gives to the spot of light the appearance of a continuous line illuminating the whole length of its more or less complicated path. The blending of colours, and other experiments with the well-known colour-top, are examples of the persistence of optical impressions on the retina.

At the Plymouth (1877) meeting of the British Association, Sylvanus Thompson, Professor of Experimental Physics in University College, Bristol, exhibited some very remarkable optical illusions, to which he gave the name "Strobic Circles." These illusions depend partly upon the persistence of impressions on the eye, and partly upon the effect of the movement of the optical image across the retina. If a set of concentric circles (Fig. 4) be drawn in black and white upon a card, so as to present the appearance of a black and white target, and the card be moved in circles

before the eye, the whole target will appear to rotate on its centre, the effect being heightened by the appearance of a hazy cross rotating in the

Fig. 4.—Strobic Circles.

same direction. This effect can be explained by the fact that those portions of the black circles which are nearly coincident with the path of motion of the card, are not by that motion blended with the white circles, and therefore remain distinct and clear; while those portions of the same circles whose direction is perpendicular to the path of the card, become confused with the white spaces, and are rendered nebulous and indistinct. It will be found that if one of these targets be moved rapidly vertically up and down, the top and the bottom portions of the circles will become hazy, while the parts to the right and left will be comparatively clear; and, similarly, the effect will be reversed if the card be moved horizontally from right to left. When, however, the card is moved in a circular path, the position of the diameter

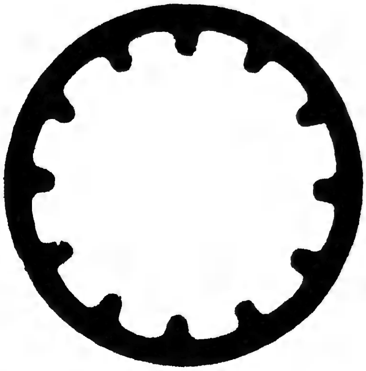

Fig. 5.—Strobic Circle Experiment.

along which the circles are blended by the movement is continually changing, rotating with the rotation of the card, and then the whole figure appears to be turning on its central axis. In Fig. 5, the effect of moving the card in a similar way is to give to the toothed wheel the appearance of rotating in the opposite direction to that in which the card is being moved.

A very remarkable series of optical illusions is derived from the influence of neighbouring forms upon one another, either by making violent contrasts, or by leading the eye to form an erroneous idea of form, size, or distance, by presenting a standard of comparison, whose tendency is to mislead. In illustration of this, let two pairs of perfectly parallel straight lines be drawn—A B and C D (Fig. 6). Outside A and B, draw two curved lines, or arcs of circles, having their concavities directed towards the parallel lines; and outside C and D draw two curves, presenting their convexities to the lines. The effect of these curves will be to destroy the appearance of parallelism

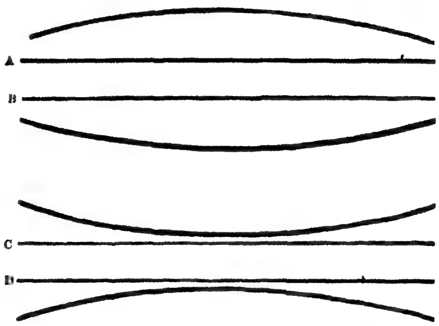


Fig. 6.—Apparent Concavity and Convexity of parallel Lines.

between the lines; A and B appearing to be closer together at the middle than at the ends, and C and D appearing to be more widely separated at the middle, and to be contracted at the ends. In this case, the eye unconsciously measures the distances between the curved and straight lines at various points along their length, and is led to assume that the variation of distance is due to a variation in direction of both lines instead of only one.

Lines drawn diagonally in alternate directions across parallel lines have the effect of destroying their appearance of parallelism. This phenomenon was first pointed out by Zöllner. It will be noticed in Fig. 7 that the vertical lines, which are perfectly parallel, appear, by contrast with the diagonal hatching, to be tapering in alternate directions. Fig. 8 is an illustration of an illusion closely related to the last. The lines C D and E F lie in the same straight line; but the effect of their being separated by the parallel straight lines A and B is to make E F appear

to be considerably higher than the line C D would be, if produced.

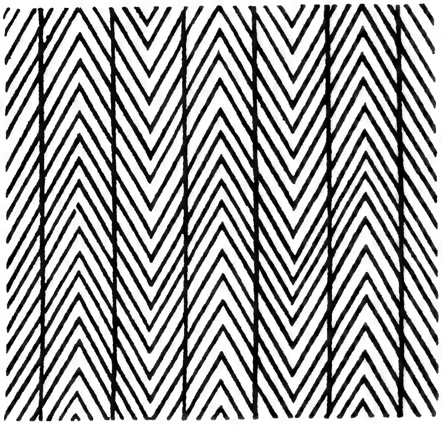

Fig. 7.—Effect of Diagonals upon Parallel Lines.

The effect of contrast upon the appearance of the relative size of objects may be shown by the following simple experiment:—Cut out two pieces of white cardboard, of the horse-shoe form shown in Fig. 9, taking care to make them in every respect exactly the same size. It will be found that, when placed in the relative positions shown in the figure, the lower horse-shoe will invariably appear the larger, which can be proved to be a delusion by their being interchanged, when that which previously looked the larger will appear the smaller. This effect is no doubt due to the fact that, in the

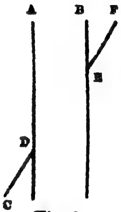


Fig. 8.

Fig. 9.—Apparent Difference in Size between two exactly similar Objects.

relative position shown in the figure, the widest part of the lower figure is in close juxtaposition to the smallest part of the upper figure; and, as comparisons are always more striking when the objects compared are near to one another than when they are remote, the eye forms its estimate of the relative sizes of the figures by comparing the parts of each which are nearest together, and the result is in favour of the lower figure.

A somewhat amusing illustration of the different estimates which the eye makes of the size of the self-same object in different positions may be made with an ordinary hat. Let a mental estimate of the height of a gentleman's hat be made, when it is on somebody's head, and let the person who has made that estimate draw a mark on the wall, at a height above the floor equal to what he thinks is the height of the hat. If now the crown of the hat be placed on the floor, with the brim against the wall, it will be found that the estimate is almost invariably too great, and that hardly one in twenty persons estimates within two inches of the correct height, some being as much as six inches out.

The relative brightness or illumination of objects affects very considerably their apparent size; light objects appearing larger than dark ones. Thus, if two equal-sized wafers—one black, and the other white—be placed side by side upon a table, the white wafer will appear to be considerably larger than the black one; and the effect is still more striking if the white wafer be placed on a black card, and the black wafer on a white card. Similarly, a white line drawn on black paper looks thicker than a black line of the same size drawn on white paper. If a branch of a tree, or a telegraph-post, be seen with the sun's disc for a background, it will appear to be carved out on each side, so as to appear narrower in that portion of its length which traverses the disc of the sun, the light of the brilliantly-illuminated background appearing to encroach beyond its legitimate boundary (see Fig. 10). And if a much narrower object than the post be looked at, with the sun behind it, it will disappear altogether, the two portions of the sun encroaching the boundary so far as to unite and obliterate the object. This phenomenon may be observed by placing the eye so that the smaller branches or twigs of a tree, or the wires from the telegraph-post, traverse the sun's disc, in which case they disappear as completely as they would if the sun were in front, instead of behind them. But perhaps the most striking illustration of the

Fig. 10.—Telegraph Post with the Sun behind it.

effect of brightness upon the apparent size of an object, which is known as *irradiation*, may be made by the following experiment:—Let a fine platinum wire, stretched between two supports, be so arranged that it can at will be rendered incandescent to whiteness by passing an electric current through it. It will be observed that a wire so small as to be invisible a short distance off will, when glowing with incandescence, be rendered not only visible, but will appear as a thick wire or rod, capable of illuminating a small room.

From the effects of contrast upon form and size, the mind is naturally led to its effect upon shade and colour. An object appears to be light when placed on a background darker than itself, and *vice versâ*. Every observer must have noticed that the flakes of snow, while falling, look white against the background formed by houses and trees, but appear to be black when seen against the sky. The following is an interesting illustration of the effect of the close juxtaposition of different shades of tone or colour:—Let a parallelogram (Fig. 11) be divided

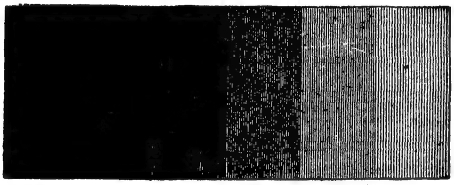

Fig. 11.—Effect of Contrast upon Shade.

by vertical lines into, say, six compartments, having previously received a light wash of Indian ink. When that is dry, let the first five divisions receive a second wash of the same colour, the first four a third wash, and so on, each succeeding wash being taken over a number of divisions which is less by one than its predecessor. The first division will, therefore, have had six washes, the second five, the third four, and so on, down to the sixth, which will have had but one faint wash of tint. The effect of contrast in this diagram is most apparent, the stripes appearing darker towards all their right-hand boundaries, being thereby contrasted with their lighter neighbours, and lighter towards their left-hand edges, where they are bounded by darker stripes. However evenly the colour may have been laid on, each division will appear to be shaded across its width from light into dark; and it is only by covering up all the other divisions that the true appearance of a uniform shade can be observed.

The illusionary effects of colours upon one another form a very important subject to painters; and the great masters of colour, Paolo Veronese, Titian, and in more recent times Turner, knew well how to use them to produce upon the eye of the spectator the effects intended to be portrayed. If a strip of red paper be placed against a strip of green paper, the brilliancy of both colours is heightened; the one supplies to the eye what the other lacks, and the fatigue which would be caused by regarding one colour is relieved by the other; so it is with the contrasted colours blue and orange and with violet and yellow; the colours in each of these pairs together constitute white light, and are, for that reason, said to be *complementary* to one another, and it is the property of all complementary colours to heighten the effect of one another by contrast.

If, however, a blue object be placed close to a yellow one, it will acquire a more violet hue, and the colour of the yellow object will incline towards orange. In looking at this contrast, the eye appreciates what is wanting in each colour to make up the constituents of white just in the same way as in comparing the lengths of two rods, placed side by side, one of which is a foot long and the other eleven inches, the eye is struck rather by the last inch in the longer rod which is wanting in the shorter than by the eleven inches which are common to both. Now, in order to bring blue and yellow to white, the blue requires the addition of yellow and red, and the yellow requires the addition of red and blue. But the effect of looking at blue is to diminish the discriminative power of the eye for blue light—in other words, to fatigue it, so that other colours have a predominating effect. The eye, therefore, after looking at blue, appreciates the colours yellow and red, or their mixture, orange, and, after looking at yellow, is more sensitive to red and blue, which constitute violet. M. Chevreul, whose researches in this subject have been very extensive, constructed a table, in which the modifications undergone by colours by being contrasted with other colours are recorded, and some of the results of his experiments are most interesting.

A more curious series of optical illusions in connection with colour comprises those that are known as *accidental* or *subjective images*. If the eye be fixed for a few moments upon a red wafer laid upon white paper, and then be suddenly turned to another part of the white ground, a spectral image of the wafer will be seen, but of a greenish tint. Similarly, a green wafer will produce a red image; in fact, gazing at an object of any bright colour will cause a spectral image of its complementary colour to appear when the eye is directed to another spot. Here, again,

the effect is produced by the flooding or fatiguing of the eye by one colour temporarily destroying its power of appreciating that colour, and rendering it proportionately more sensitive to the remaining or complementary hues. The white ground may be looked upon as a mixture of all the colours, or, for convenience, of the primaries, red, blue, and yellow. If, then, after the sensibility of the retina for red has been diminished by gazing at a red object, the eye be directed to a white surface, that portion of the retina which has been fatigued will see in the white ground only the blue and the yellow, being more or less blind to the red, but the surrounding portions of the retina which have not been so fatigued will be able to appreciate the white ground in its integrity. Thus the real image of a red wafer on a white ground is succeeded by a spectral image on a white ground of a green wafer. In all these cases the brain notices just what constitutes the difference between the colour of the object gazed upon and that of the ground upon which the spectral image is formed. An analogous illusion of another sense—the taste—will, perhaps, explain this phenomenon. A mixture of sugar and common salt will appear sweet to a person who has just tasted a solution of salt, but it will seem to be salt if sugar have been previously tasted. Here, then, is an instance of one and the same compound substance having apparently two distinct flavours, according as the organs of taste have been fatigued by one or the other of its constituents. This may be compared with the colour experiment; the white corresponds to the mixture, and the red and the green, its two separate constituents, to the salt and to the sugar. Sudden contrast will cause a mixture of red and green to appear green after seeing red, and red after seeing green. There are, however, instances of analogous illusions by contrast in all the senses.

At the meeting of the British Association, which was held at York in the year 1844, the late Sir Charles Wheatstone exhibited a very curious chromatic illusion, to which he gave the name of "Fluttering Hearts." Upon a greenish-blue ground were painted in bright scarlet a number of hearts. When this was viewed in the brilliant light of a beam of sunshine coming through a hole in a shutter in an otherwise dark room, the hearts appeared to flutter over the paper, producing a very extraordinary and dazzling effect. The explanation of this phenomenon must be sought in the inability of the eye to focus itself at the same moment for two colours of so great a difference of refrangibility as blue and red. We need not remind our readers that if a beam of light be passed through a prism it will be split up into its constituent colours, forming upon a screen a figure which is called a *spectrum*. Now, as this separation of the colours is due to some being more diverted than others from their original path during their passage through the prism, it follows that a refracting instrument, such as a magnifying-glass, must be focussed differently for different colours. The eye is such a refracting instrument, but although it possesses, as was pointed out in the beginning of this paper, a marvellous facility for adjusting itself in focus, yet some time must be occupied in making the change; and in looking at the "Fluttering Hearts" diagram, a succession of adjustments and readjustments in focus for the red and for the blue take place with great rapidity, giving a fluttering appearance to the hearts, and accompanied after a short time by a painful sensation of fatigue.

Deceptive impressions may be produced either from the want of magnifying power in the eye for small objects by which their structure could be detected, or from the want of power to discern the details of objects at a distance. Of the former, instances may be cited in the white opacity of milk and the crimson appearance of blood. Both these animal fluids consist in reality of a vast number of ovoid bodies suspended in a clear and almost colourless medium; and in the case of milk these bodies are almost as transparent and colourless as the medium in which they are suspended, but as the unassisted eye is not able to detect these minute bodies, the rays reflected from them and from the colourless medium become so intermingled as to present the appearance of a homogeneous colour. If a circle, one inch in diameter, coloured in alternate straight stripes of red and blue, each about one-fiftieth of an inch in thickness, be viewed from a distance of a few feet, the distinction between the stripes will become entirely lost; their colours will be blended, and the disc will appear as if coloured by a uniform wash of violet colour; if the stripes be wider, the same effect will be produced, but at a greater distance of observation.

All the foregoing illusions can be observed equally well with one eye as with two; but there is a very large and important class of optical illusions which depend upon the phenomena connected with binocular vision, or the simultaneous use of the two eyes. A very amusing and at the same time very striking experiment is the following:—Let a tube,

about three-quarters of an inch in diameter, be formed by rolling up a sheet of writing-paper; keeping both eyes open, look through the tube with the right eye, and with the other look at the palm of the left hand placed against the side of the tube at a spot about the middle of its length. The effect is almost magical, for the hand appears as if a hole of the diameter of the tube had been cut through it, through which objects may be seen; and with this simple apparatus many interesting modifications of the experiment may be made.

The well-known optical instrument, the Stereoscope, has for its sole object the production of optical illusions of great beauty, and is too familiar to require any description. The principle of its action is derived entirely from the phenomena attending binocular vision. If a cube standing on a table be viewed from different sides of the room, two different pictures of it will be obtained, one taking in more of the right-hand face, and less of the left, and the other more of the left-hand face, and less of the right. The same applies in a less degree to the appearance of objects when seen by one eye or by the other—a slightly different view is obtained, the one letting in a little more of the one side, and the other a little more of the other; and it is by the union of these two views that the appearance of solidity is obtained. But, besides seeing to a certain extent round an object, there must be a difference of convergence of the axis of the eyes when looking at objects at different distances. This is apparent in the case of a man trying to look with both eyes at the point of his own nose; the convergence in that case is so great as to be painful, and he is said to squint; and as the distance of the object looked at increases, so the convergence decreases, but never entirely disappears. The diagram shown in Fig. 12 will make this clear.

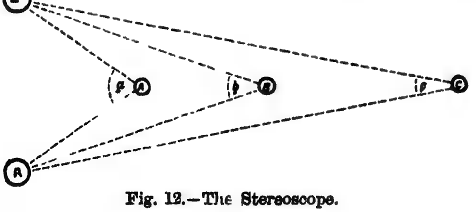

Fig. 12.—The Stereoscope.

Let L and R represent the left and right eyes, respectively. If an object be placed at A, the convergence of the optic axes of the eyes will be equal to the angle *a*; if the object be removed to C, the angle of convergence will be reduced to the angle *c*; and at any point (B), intermediate between the two, the angle of convergence *b* will be larger than *c*, and smaller than *a*.

Now, the stereoscope is an instrument which, by means of either prisms or reflectors, assists the eyes to combine pairs of dissimilar pictures, so as to convey to the mind the impression of only one view; and as the two pictures so combined represent the object seen by the two eyes respectively, the combination produces in the brain the impression not of two flat pictures, but of one solid object in relief. In order to heighten the effect, in preparing the pictures, the distance between the eyes is, in practice, assumed to be much greater than it is in reality.

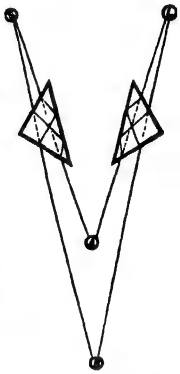

Fig. 13.—The Pseudoscope.

It has been shown, in reference to Fig. 12, that it is mainly to the degree of convergence of the optic axes of the eyes, that the mind is enabled to judge of distance. The more a man has to squint in order to see an object, the nearer it must be to him. It is clear, then, that if by any means this order of things could be reversed—if by looking through an instrument the angle of convergence could be increased with an increase of distance—then near objects would appear farther off than distant objects, and everything would appear to be turned inside out. The Pseudoscope is an instrument also devised by Sir Charles Wheatstone for producing this result, and of all optical illusions, those produced by this instrument are, perhaps, the most extraordinary and striking. It consists (see Fig. 13) of two rectangular prisms of glass fixed at such an angle that the relative direction of rays reaching the eyes from objects seen through them is laterally inverted by internal reflection, so that the convergence of the optic axes increases with the distance of the object looked at, and *vice versâ*. If a globe be looked at through the pseudoscope, it appears like a concave cup, because the point on the globe nearest the eye appears farthest off, and parts farther off appear nearer in the inverse order of their distance. Similarly, the inside of a basin appears like a globe, and a hat appears to be turned completely inside out: this last illusion is far more difficult to see in perfection, on account of the great difficulty of overcoming the inherent conviction that the contrary is the case. If, however, a hat be specially made with the lining outside, the delusion is instant and complete. For the same

reason, although a bust appears through this instrument as a hollow mask, it is absolutely impossible to obtain a similar delusion with the living human face.

In the preceding pages no mention has been made of the deceptions produced by reflectors or other optical contrivances, such as the effect known as "Pepper's Ghost," and other experiments of that class. These are not, strictly speaking, illusions at all, but are simply applications of optical principles for producing perfectly regular physical results. The effects of a common looking-glass can hardly be called optical illusions, although they convey the impression that a second self is standing as far behind the mirror as the observer is in front; and the removal of the silvering from the glass, which would make it identical with the apparatus employed for producing the "Ghost" effect, would not bring it within the legitimate scope of this paper. Nor has it been deemed necessary to describe those optical toys and contrivances, such as the apparatus for apparently seeing through a brick, which, by means of reflectors, simply diverts the beam of light *round* the obstruction, whether it be a brick or anything else.

The celebrated *Fata Morgana* of the Straits of Messina, in which a spectator on shore sees images in the sky of men, houses, trees, and ships, is a special instance of the phenomenon known as the *Mirage*, in which, in certain thermal conditions of the atmosphere, reflection takes place from the bounding surfaces of laminæ of different densities, as from the surface of a sheet of water, and very remarkable effects are produced. All these phenomena are physical rather than physiological, and only on account of their abnormal appearance and rare occurrence can they be called optical illusions.

Those extraordinary and rare phenomena in Nature which are called "*Mock Suns*" or parhelia (see Fig. 15), chiefly seen in the Arctic and Antarctic regions, owe their origin, like the rainbow, to reflection by particles of water, but, unlike the rainbow, those particles are in their crystalline or frozen condition. The phenomena of *halos* and *coronæ* are caused partly by diffraction in the aqueous particles constituting a misty atmosphere, and partly by reflection and decomposition of light, as produced in the rainbow.

Fig. 14.—An Effect of Mirage observed by Captain Scoresby, while cruising off the Coast of Greenland in 1822.

The celebrated *Spectre of the Brocken*, to be seen in the Hartz Mountains, under favourable conditions, is nothing more than the shadow of the observer cast by the rays of the rising sun upon the mists lying in the valleys below, and cannot, therefore, be classed among illusionary effects.

The useful applications of optical illusions are not numerous, being almost exclusively employed for scenic effects and for decorative purposes. Every picture is by its very nature made up of optical

illusions; and the more perfect the illusive effect, the greater, of course, is its merit. The science of perspective teaches the principles upon which a very important branch of the illusionary effects of the painter's art is produced; and scenic effects upon the stage depend in a great measure upon an exaggeration of the effects of perspective. For instance, for the purpose of giving to the stage greater apparent depth, the floor is made higher at the back of the stage than it is towards the auditorium, and the side walls in an interior taper both vertically and horizontally from the front to the back. For a similar reason, an avenue of trees planted in two tapering straight lines appears longer or shorter according as it is viewed from the wider or the narrower end: in the one case, the tapering of the avenue adds to the effects of perspective, and exaggerates them; and in the other, it subtracts from, and to a certain extent neutralises them.

We cannot conclude this paper without mentioning an interesting optical experiment which, though hardly to be classed among optical illusions, is closely related to them. It has been pointed out that the nerve-filaments of the retina diverge from a common centre, to which is attached the optic nerve leading to the brain. It is a curious fact that this spot, instead of being, as might have been supposed, the most sensitive to optical impressions, is absolutely and totally blind, as may be proved by the following experiment:—Let two small black wafers or discs be placed on a sheet of white paper, about four and a half inches apart, then let the left eye be closed and the right eye be fixed on the left-hand wafer. If now the head be steadily drawn back from the sheet of paper, a point will be reached at which the right-hand wafer becomes totally invisible, and it will continue so over a short range, while the distance is increasing, becoming again visible when the further limit of that range is passed. On again slowly approaching the paper, the effects reappear in their inverse order. With a distance between the spots of four and a half inches, the usual range of invisibility is between the distances of ten and twenty inches from the paper.

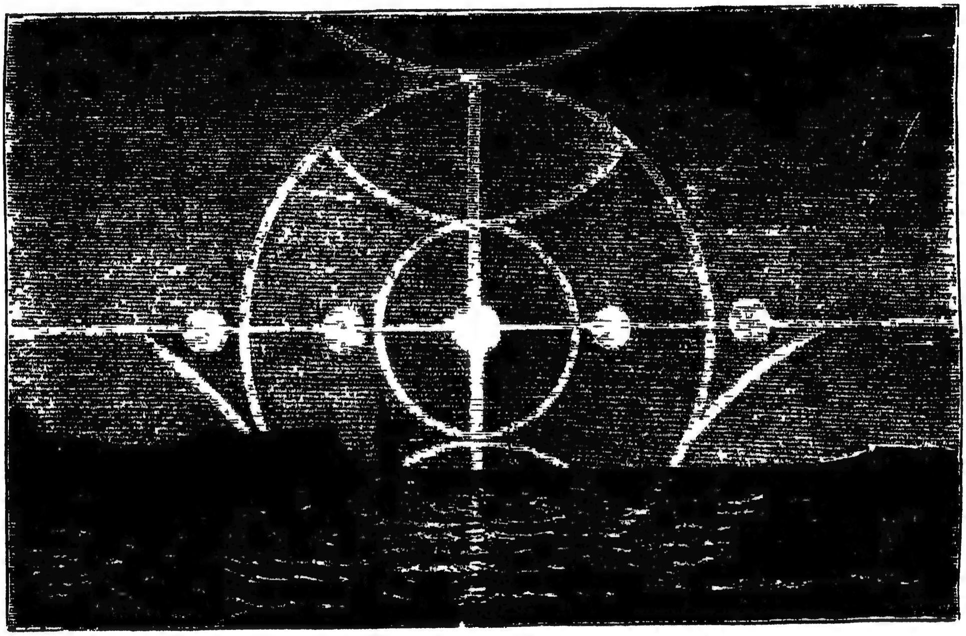

Fig 15.—Parhelia, or Mock Suns.

It is impossible, within the limits of the space at our disposal, to do more than mention some of the more characteristic of the abnormal phenomena connected with vision, which together form a most interesting branch of physiological inquiry. We trust, however, that, notwithstanding many and perhaps obvious omissions, a sufficient number have been recorded in this paper to suggest further experiments, and that the reader may be led by them to investigate the subject for himself.

# NERVES OR NO NERVES? OR, THE ART OF FEELING.

By Andrew Wilson, Ph.D., F.R.S.E., F.L.S, etc.

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LIKE many other curious functions of our bodies, the art of feeling and of exercising sensation loses its wonder, and ceases to interest us, because of its common nature. It is, however, the special gift of science to show the wonders which exist within the most limited field of observation, and in the most common objects which surround us. Within the confines of the human body there are exemplified, it is true, problems of matter and of mind which the farthest flights of scientific philosophy have as yet failed to explain. But it is equally true that there are many points in our own history and daily life which this same philosophy has fully elucidated, and which have been shown, notwithstanding their familiarity, to present elements of great interest and of sound instruction. Of such familiar points, the ordinary course of nerve-action and sensation are good examples. No fact in our personal history is clearer than that which shows, as the result of experience, that we are able to gain a certain amount of knowledge of the world around us. To this knowledge we are enabled to attain, through the exercise of our "senses"; and our "senses"—whatever these may prove to be—are known in their turn to be parts of our nervous system. In each act of our daily life, no matter how trivial, simple, or how oft-repeated the act may be, the nervous system plays a part. The very beating of the heart—carried on involuntarily and often unconsciously, as in sleep—the winking of an eyelid, and the thinking a thought, are each and all carried out under the supervision of and controlled by the nervous system. Thus we discover that this system is that whereby we are brought "into relation" with the world around us. The higher the nervous system, the more perfect is the relationship which it maintains between its possessor and the outer universe. And hence for all purposes of scientific definition, as well as to popularly designate the use of the nervous system, we may say that it performs the "*function of relation*," and brings its possessor into contact with the surrounding world.

It is an obvious conclusion, however, that the manner in which the functions of nerves are exercised is seen to be subject to striking variations as we survey the wide domain of animal life, and include in our glance the lowly animalcule, and the "lord of creation"—man himself. The acts of an animalcule are simple indeed, as compared with the complex actions which mark the daily life of man; and still greater do the differences appear which seem to separate the apparently non-sensitive plant from its sensitive animal neighbour. But the physiologist might after all show that the differences between most of the nervous actions of man and those of lower animals are more apparent than real. And he might go farther still, and assert that the plant-world should not and may not be left outside the category of sensitive things of nature. He would endeavour to show that there exist plain grounds for the belief that sensation is not confined to the animal world, and that plants may "feel," and may act upon their feelings and sensations, as do animals; Whilst, more extraordinary still, the man of science might inform us that the presence of nerves was not a necessary condition for the due exercise of sensation; and that, in short, many animals and plants "feel," in the entire absence of nerves. Hence it would seem that the common "art of feeling" constitutes, after all, a most singular phase in the history of living beings; and the brief investigation of the subject may, therefore, afford a reply to the interesting question which forms the title to the present paper.

A brief study of the features involved in the common exercise of the nervous system in man, may fitly preface a wider glance at the subject of the relations of nerves and nerve-action in living beings at large. When we touch a table, for instance, what features are involved in the action, and how is the act itself inaugurated and carried out? Starting with the assumption that the action has originated in a "thought" or "idea" generated in the brain—for there are some philosophers who would maintain that this thought is but the outcome and product of antecedent thought or nerve-action—we find the "idea" to give origin to "nerve-force" or "nerve-impulse." What this "nerve-force" is we cannot tell; nor has it been made plain how a thought becomes transformed into the force which has the power of calling our muscles into play, and, it may be, of exciting the most violent bodily action. Somehow or other, however, the idea is so

transformed; and, stranger still, it is actually directed and guided, as if by the hand of a skilful pointsman, into the particular channel or nerve we wish. If we wish to employ the fore-finger in touching the table, the nerve-force is directed through the appropriate nerves to this particular member. If the middle finger is the desired member, the nerve-force will affect it—right hand or left, one finger or all, it matters not which to the brain-pointsman—the nerve-force is directed unerringly to the particular portion of our frame we desire to affect. Thus, one of the most familiar acts and powers of our daily life—the power to do as we choose, to lift this finger or that—is really performed through a mechanism so subtle and incomprehensible, that the greatest authorities of our day own their inability to solve its depths, and admit their helplessness with the best grace possible.

Through the nerves, then, flows this wonder-force, of which, indeed, thought itself is but a modification. Flashing down the arm and finger, it intrudes itself upon the muscles thereof. Rousing them from their state of rest, it calls upon them to contract, and, like a stern taskmaster that brooks no opposition, insists on the instant execution of its commands. The willing muscles obey; the arm and finger are duly moved, and the latter member is brought into contact with the table. The desired action has thus been accomplished, you say, through the transformation of thought or brain-force into nerve-force, through the transmission of this force to the muscles, and through the subsequent stimulation, contraction, and movement of these latter structures. So far, the steps of the action are clear enough. But this is not all. The details just given, literally involve only one-half of the action of touching the table. How do you know you have touched the object in question? You reply, "Because I see I have touched the table, and because I feel I have touched it." Just so; but "feeling" and "seeing" are both nervous acts, involving actions as complicated as those through which you set your muscles to work. Suppose, for the sake of clearness, that a blind man touches the table. His knowledge of that part of the outer world represented by the table is gained by one sense only—that of touch. How does he know he has touched the table? Again you reply, "Because he felt it." And what is feeling, and how does he feel? To answer these queries we must try to understand what these "senses" of ours are, and what the possession of a "sense"—such as that of touch—implies. Professor George Wilson long ago called the senses the "gateways of knowledge," and the term is an exceedingly appropriate one. For through these five or six gateways comes information upon all manner of subjects—"information received" in fact, and upon which, like sagacious policemen, we are bound to act.

Now "touch" is of all the senses the most diffused, and of all our knowledge-gateways the widest. A little cogitation makes it clear that the sense of touch—that is, the sensation produced by our contact with the table—is not confined to the nerves situated in the skin of the finger. And a little further thought will result in the idea that before we can "know" anything about the table, the brain must have been duly informed of what is going on at the tip of the finger. In the blind man the gateway of the eye is closed, and it is therefore through the finger and the sense of touch alone that information can be conveyed to his brain. How, then, is this very necessary communication effected? The nerves supplying the finger, and indeed, all the ordinary nerves of the body, are composed of two kinds of fibres, named *motor* and *sensory fibres*, respectively. These fibres are indistinguishable as they exist in a nerve, although, at the point where the nerves leave the spinal marrow, these two kinds of fibres are separate and distinct, and exist as the "anterior" and "posterior roots" of the main nervous trunks. The functions of the two varieties of fibres are widely different. Through the one set, named *motor fibres*, impulses flash *outwards*, or *from* the brain *to* the muscles. Through the other

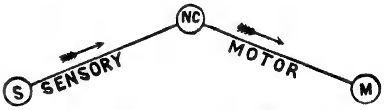

**Fig. 1.—Diagram illustrating the Mode of conveying Impressions to and from the Brain.**

set—the *sensory fibres*—impulses are conveyed *inwards*, *from* the outer parts of the body, and *from* its muscles to the *brain* or other chief centre of the nervous system. Thus then, it becomes clear to us that when we wished to touch the table, the nerve-impulse which set our muscles in *motion* flashed from the brain through the *motor* fibres of our nerves; and that conversely, we became aware that we had touched the table, because the *sensation* of touch—produced by the contact of the finger with the table—was transmitted to the brain through the other or *sensory* fibres of the nerves. In like manner, if we had seen our finger touch the table, the eye would have then served as a great sensory organ. Hence arises the idea of its exercising

a *sense*—seeing that it conveys *to* the brain information regarding the work and functions of the finger and its muscles. Or, supposing that a person passes his hand quickly before our eyes, we withdraw our head and instinctively close the eyelids. Here the sensory impulse has passed (Fig. 1) from the eye (*s*) to the nerve-centre or brain (*nc*), and has thence been "reflected" as a motor-impulse to the muscles of neck and eyelids (*m*). We must, therefore, note, that in every nervous action there are two aspects involved. The impulse sent outwards is ultimately *reflected* inwards, and carries with it to the brain the knowledge of what is going on without. This is what physiologists know under the name of *reflex action;* and it can well be understood from the foregoing examples, that most of our actions are regulated and performed in conformity with the plain principle of impulses being "reflected" inwards or outwards, as the case may be.

That the impulse which determines the bodily actions does not always originate in the brain, is a fact which becomes clear to us when we consider that we are acted upon in various fashions by the outer world, and have in turn, and as the result of the impressions we receive, to react upon the world. Why does the sight of some tit-bits in the way of dainty food cause a flow of saliva, or, in plain language, "make the mouth water"? Because the sensory impulse received by the eye has been transmitted to the brain, and "reflected" therefrom to the nerves of the salivary glands in the mouth, with the result of causing a flow of their secretion, such as would ensue were the savoury morsel to be eaten. A story is related of a distinguished chemist, which illustrates in a remarkable manner, not merely the theory of "reflex action" just discussed, but also the rapidity with which bodily action may follow the receipt and transference of nervous impressions. The chemist in question was engaged in examining the contents of a phial, when these contents suddenly exploded, and the bottle was dashed from his hand into a thousand fragments. He was conscious of seeing the flash which accompanied the explosion; and in the immeasurably short interval which elapsed between the explosion and the unclosing of his eyelids, came the agonising thought that possibly he was blinded for life. A moment later, on opening his eyelids, he found, to his immense relief, that his eyes were uninjured; but on the outside of his eyelids and in his face were small particles of glass. This latter observation, therefore, showed that, notwithstanding the extreme shortness of the interval which elapsed between the flash of light and the shattering of the glass, his eye had still had time to warn the brain of its danger, through a *sensory* impression; and the brain had also contrived in the interval, and through a *motor* impulse, to issue a command to the muscles of the eyelids to close, and to protect the delicate organs under their care—as illustrated by Fig. 1.

Such is a short account of the essential phases in human nerve-action, and in that of allied animals as well. Reflex action in reality forms the basis, as has been already remarked, of our daily walk and conversation, and may often be carried on automatically, or unconsciously to ourselves, and through the influence of that power of habit which has well been termed a "second nature." The considerations which follow upon the investigation of the manner in which the highest animals maintain relations with the world around them, invite us to glance at the nervous acts of lower forms of life, and to compare their actions with those of their higher neighbours. Let us, for instance, select that well-known animalcule the *Amœba*, or "Proteus animalcule," or its ally, portrayed in Fig. 2, as a first object for study. The

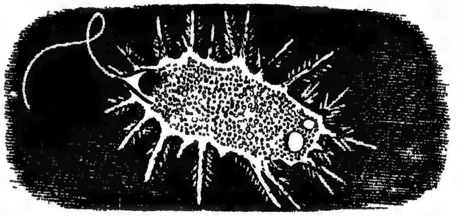

Fig. 2.—*Mastigamœba aspersa*—a fresh-water Transition Form between the *Amœbæ* and the *Flagellatæ*. (*After F. E. Schulze.*)

amœba slowly moves about in a little sea of its own, formed by a drop of water taken from a stagnant ditch—a curious, shapeless speck of living jelly, without organs or parts, and which, as we watch it even for a few minutes, seems to flow continually from one form into another. The amœba—this microscopic speck of structureless living matter—is, notwithstanding the simplicity of its body, a veritable animal, that lives to and for itself as completely and as perfectly as does the highest of beings. You see a particle of solid matter approaching the amœba, and now, it has just touched the margin of the soft, jelly-like body. The animalcule acts most characteristically; for it proceeds thereafter to inclose the food-particle with its body, and literally flows around the particle, which is seen to be finally engulfed within the soft substance, amidst which, if digestible at all, it will be slowly dissolved. What shall we say of the amœba's act and behaviour to the food-particle? Simply that the

animalcule "felt" the contact of its body with the particle, and that it acted—unconsciously, no doubt, but like man nevertheless—upon "information received," and seized upon the substance for food. This appears exceedingly like "reflex action" in a lower phase after all, for here you see an impression received from without, and you also behold action of a definite kind from within to follow the receipt of that impression. We may not dogmatise regarding the nerve-functions, or "irritability," as the nervous sense is termed, of an amœba; but this much we may affirm with safety, that the soft tissue of the structureless and nerveless body is sensitive, and that its sensitiveness may be, and is, excited in

Fig 3.—*Chrysaora*, a Medusoid.

a general manner by the contact of the outer world and its belongings.

The summer sea around our coasts teems with many beings of graceful form and appearance, but with none more beautiful to the eye or interesting to the mind than the "Jelly-fishes" or *Medusæ*, whose delicate glassy bodies are so near akin in delicacy to the water amidst which they float, and which drain away in your hand as you attempt to lift them from the sea. Here is one form (Fig. 3) which comes sailing along through the still sea, expanding and contracting its bell-shaped body, with a regularity which is both surprising and noteworthy in a being of so lowly a grade. From the roof of the bell hangs a tongue or clapper; around its margin you may see little specks of pigment, which are *ocelli* or rudimentary eyes; and you may notice tentacles or feelers as well. A sheet of contractile tissue lines the interior of the bell, and covers the "tongue." By the contraction of this delicate layer, the walls of the body are drawn together and water is ejected from its mouth, the animal being thus propelled forwards; whilst the subsequent enlargement and dilatation of the bell results in an inflow and re-expulsion of water. In this way, by alternately expanding and contracting its body, our medusa pulsates through the water, like a veritable creature of fairy organisation and of almost ethereal nature. Let us interrogate the jelly-fish by experiments similar to those carried out by Dr. G. J. Romanes, and inquire as to the means it possesses for maintaining relations with the outer world. We must dismiss from our minds, in dealing with the medusa, any idea of "consciousness," or the knowledge of the why and wherefore of our actions which is so characteristic of man. For the lower animals perform the actions of their life under unconscious stimulation from without, and without necessarily knowing or appreciating the reasons of their acts. With a needle or other sharp instrument, prick the side of the bell-shaped body of

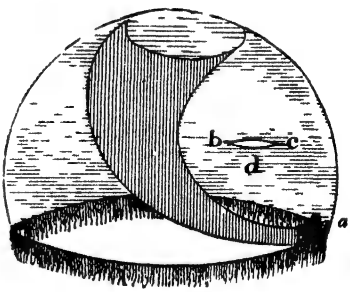


Fig. 4.—*Tiaropsis indicans* (*after Romanes*), showing the central Mouth (*a*) moved to the Point which has been touched.

the jelly-fish (Fig. 4), and you will find that the central tongue or clapper of the bell bearing the mouth will move to the irritated point (*a*) just as the indicator of a dial moves in response to the mechanism whose working it is meant to indicate. Prick another part of the bell, and the mouth will move unerringly to the second point you have touched. Such a result shows us clearly, not only that the jelly-fish feels, and that acutely, but that through reflex action it is enabled to respond to the stimuli by the movements of its mouth, and in an accurate manner to indicate the points which have been touched. In some medusæ, the reason for the movement of the mouth to the point which has been touched is ex-

plained when we discover that the mouth is provided with a stinging apparatus, which, by the movements alluded to, would be brought in contact with any foreign object or animal touching the body of the jelly-fish. Suppose that now we make a cross-cut in the side of the jelly-fish (Fig. 4, *b c*), and sever the delicate body-substance through a limited part of its extent; and, further, that we prick the body below the incis as at *d*—that is, on the side of the cut farthest from the mouth. We may then see the mouth to move about in an erratic fashion, as if quite at sea, and at a loss to discern the exact point which has been irritated.

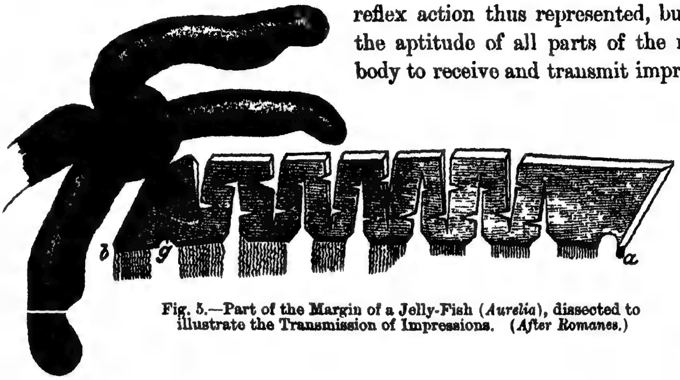


Fig. 5.—Part of the Margin of a Jelly-Fish (*Aurelia*), dissected to illustrate the Transmission of Impressions. (*After Romanes.*)

The explanation of these facts must be prefaced by the announcement that no definite nerves are to be discerned in the vast majority of our jelly-fishes. It is thus essentially like the amœba—sensitive in the absence of well-defined nerves, such as are the natural heritage of animals higher in the scale. This fact alone is curious and noteworthy, and bears a distinct relation to certain conclusions to be drawn at the close of our investigation. We may firstly form some idea of the manner in which the medusa contrives to indicate the point of its body which is touched, by assuming that the impressions or sensations are conveyed from the exterior of the body to the central mouth through definite tracts or lines—"lines of discharge," as they are called. And, *secondly*, this idea is supported by the experiment just alluded to. Since when the line along which the nervous impulse travels is interrupted by a cross cut, the information is conveyed to the central mouth in a roundabout fashion, the impulses scattering themselves, as it were, over the body, and in such an incomplete manner, that it is unable to indicate as correctly as before the seat of the irritation. In an experiment of Dr. Romanes', the bell of a jelly-fish was cut, as exhibited in Fig. 5, into "a continuous parallelogram," and then divided as shown in the illustration. When any point, such as *a*, in this divided portion was stimulated, a wave of contraction passed to *b*, proving that the "wave of stimulation" must have passed round and round the ends of all the intervening cuts. When the wave reached *b*, near which a nerve-mass or ganglion (*g*) is situated, it will be "reflected" from this nerve-centre backwards to *a*. Not only do we find the principle of reflex action thus represented, but we also witness the aptitude of all parts of the medusa's sensitive body to receive and transmit impressions. We find in the jelly-fish, in short, when its tissues are divided, much the same kind of effect that ensues in higher animals, in parts supplied by any special nerve, when that nerve has been divided, or otherwise injured. In such a case impressions would have to be conveyed in a roundabout manner, and in an irregular fashion to the part in question. We may conclude our survey of the jelly-fish by noting, *thirdly*, its evidently superior organisation to the amœba; and the part result of this higher structure is shown in the more definite and exact manner in which the impulses are conveyed from outward to inward parts; these impulses in amœbæ being undetermined in their direction, and very general in their scope and extent. Whilst, *fourthly*, we have noted that the principle of reflex action appears to be carried out in the medusa in much the same fashion, as regards its working, as in man himself.

A step upwards in the scale of animal life would bring before us animals in which definite nerves are developed, these nerves merely representing a higher development of the primitive "lines of discharge" along which the nerve-impulses of jelly-fish and amœba alike are believed to proceed. But leaving the higher animals, as somewhat beyond the pale of our present inquiry, let us inquire whether the plant world gives any affirmative response to the question of "Nerves or no Nerves?" The flower we pull to pieces shows no sign of feeling—leaving "pain," as perfectly distinct from mere feeling, entirely out of sight—since, in the absence of consciousness in any form, "pain," as judged by the human standard, must be regarded as non-existent. As a rule, therefore, the plant world gives no response to outward stimulation. But are we to conclude from this observation that

plants, as plants, are utterly destitute of feeling or sensation? By no means. Since a sponge gives no response when it is cut in pieces, and the sponge is a true animal, whose living parts exactly resemble amœbæ in nature and constitution. Moreover, if the absence of nerves in plants is to be held as negative evidence, testifying in favour of their non-sensitive nature, we might equally well maintain that all the lower animals should be non-sensitive, since they do not possess nerves—a statement manifestly absurd. But is it true that plants are invariably destitute of feeling? Ask the botanist what he can tell us about the sensitive plants, or *Mimosæ*, or about the Venus' fly-trap (*Dionæa*—Fig. 6), not

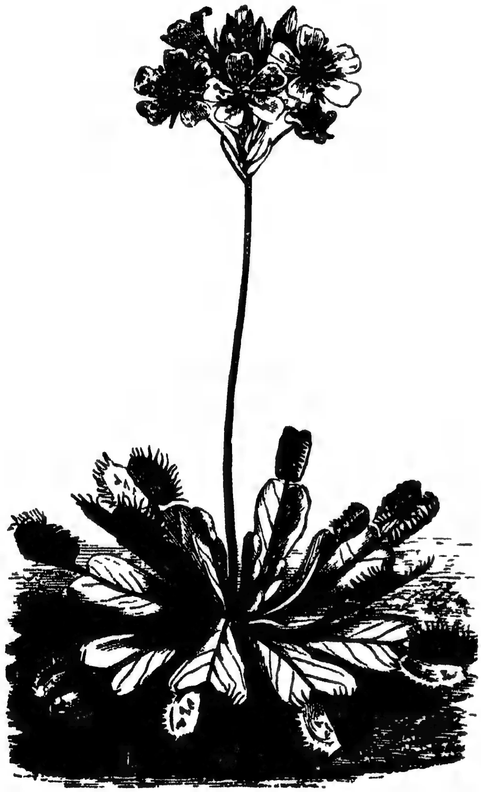

Fig 6.—Venus' Fly-Trap (*Dionæa*).

to mention the wood-sorrel (*Oxalis*) and the *Hedysarum*, or moving plant, as well as numerous other examples of plants, which literally shrink and droop their leaves when you touch them,* which capture insects for food by aid of their sensitive leaves (as in *Dionæa*), and which exhibit (as in the case of the last-mentioned plant) continual movements of their leaves—movements affected by varying conditions of temperature and other external influences. Shall we say that a sensitive plant which droops its leaves on the slightest touch, and which may be chloroformed and rendered insensible like an animal, is non-sensitive, judged by the animal standard? Or shall we hold that its actions are in any way different from those of the animal sea-anemone—apparently nerveless like the jelly-fish and plant—and which, when touched, folds up its tentacles and contracts its body into a coloured mass, looking like nothing so much as one of the curiosities in the way of jellies or ices one sees in a confectioner's window? Assuredly not, must be our reply. There is no justification whatever for assuming that plant sensitiveness is in any way different from animal sensitiveness, whilst there is every justification for maintaining the uniform nature of sensation in animals and plants, and for the essentially "reflex" nature of the acts of both. Nay, we may go farther still, and assume that could we but glance with the far-seeing gaze of imaginative science into the nature of plants and animals of the lowest grade, we should find that nowhere does life exist without sensation and feeling, or without the means for reacting in some way—however humble or ill-defined the fashion may be—on the world which acts upon and affects every living body. Sensation in this view becomes synonymous with life; and the acts of an animalcule, along with the usually scarce-perceived sensitiveness of the plant, become thus connected in an unbroken chain with the loftiest thoughts and aspirations of man.

The conclusions to which our study tends have already been pointed out in the course of our remarks. Sufficient for our present purpose is it to remark: *firstly*, our recognition of "reflex action" as a guiding principle in the common acts of man's life; *secondly*, the extension of this principle to explain the acts of lower animals; *thirdly*, that we may find "nervous" acts performed (as in amœba, the jelly-fish, in lower animals generally, and in plants) in the absence of actual nerves; whilst we may, lastly, note that having regard to the facts of well-defined sensation and movements in many plants, and to the analogies of life at large, it may be assumed that all living organisms without exception possess sensitiveness of degrees varying according to their rank and grade in the scale of being. The answer to our question of "Nerves or no Nerves?" is, therefore, clearly expressed. The art of feeling and sensation may be carried on in the utter absence of nerves and these structures

* Brown's "Manual of Botany," p. 560, *et seq.*

are themselves simply the evidence of the highest development of the sensations of lower and nerveless forms. Such a study may thus not only afford some curious information regarding the habits of life in man and lower beings, but may also show us the marvellous mystery and exceeding interest which prevail amidst the simplicity and beginnings of life.

# HOW ELECTRICITY IS MEASURED.

By Park Benjamin, Ph.D.

ELECTRICITY is supposed to be a certain and peculiar form of the energy which pervades the universe. What it really is, nobody knows. We speak of it as if it were some *thing*, but it has no tangible existence. Heat we know as a mode of motion which results in a certain condition of the body affected, and we can express that condition by a simple standard of measurement which indicates differences in degree. But we do not speak of degrees of electricity, nor think of electricity in any such way. On the contrary, we figure to ourselves electrical currents flowing like water along their conductors and in certain definite directions; or we refer to the storage and accumulation of electricity, as if it were matter which could be impounded like water in a reservoir, or oil in tanks, or goods in a warehouse.

But, at the same time, it is as well to remember that we are not at all sure that electricity has any existence apart from its conductor, that there is any such manifestation of it as a current, or that it moves at all, or that, if it does move, it travels in the direction we think it does. All that we really know is that when both a body *and the space around it* appear in a certain different state from common—possessing seemingly properties which they do not generally possess—then we say or consider that the body is in an "electrical" condition.

Now the effects of this change of condition of a body, or the space around it, are often very marked, tremendously so sometimes; and that they are of immense importance to the world it is needless to say, since we depend upon them for the telegraph and telephone, and the electric light and the electric motor, and so on through all the applications of this unknown form of energy—past, present, or to come. We have found out, moreover, that, like all other forms of universal energy, electricity is directly correlated to other forms of energy, so that we can convert other forms of energy into electricity, and *vice versâ*. Thus in the galvanic cell we convert the energy of chemical reaction (affinity) into electrical energy. In the steam boiler, chemical energy becomes converted into heat energy; heat energy in the steam engine becomes changed into mechanical energy; and mechanical energy through the dynamo becomes transmuted into electrical energy. All this involves work; it costs time and money and material; and so it follows, that unless we can measure electrical energy with a facility approaching that with which we can measure mechanical energy or heat energy, we have no means of knowing whether or not our time, money, and material are profitably expended. "Science," it has been well said, "is measurement." Electricity unmeasured, for centuries appeared to the world, even in the learned treatises, as represented by a heterogeneous mass of isolated happenings, very mysterious and wonderful, but no more so than the tricks of the magicians, and of no more utility to mankind; electricity measured, is already rivalling steam in performing the world's work, and will in time replace it.

But how are we to measure a thing, or a condition, or whatever it is, when we know nothing about it? If we are to measure the speed of a horse, we at least know that the horse is there and that he is moving, and moving in a certain direction. If we want to know how much water there is in a bucket, there is no question about the presence of the water and of the bucket. What should we think of the querist who should ask us to determine these questions, and in the same breath should deny the materiality of the horse, or the physical entity of the water; or should request us to find out the strength of a current of very doubtful existence in something which is not a thing? This is apparently what we undertake to do when we attempt to measure electricity; that is, so long as we carry with us our wrong ideas as to its nature. Suppose therefore for a moment we simply look at the *condition*,

which, as before stated, is all that we are really sure about: a body and a space around that body, in which body and space something unusual is visibly or demonstrably occurring. What is occurring?

1. The body is heated.

2. If it is part solid and part liquid, the liquid is decomposed.

3. The solid conductor becomes magnetic; it will deflect a suspended magnet and will magnetise bits of iron brought near it. It will make iron filings arrange themselves around it in curious whirls, as if all about that conductor there were some strange field of force, some atmosphere of strains and stresses which seizes upon those filings as a whirlwind seizes upon straws and dust. A water current can do work only in its path. An electrical current can do work not only in its path, but out of it. The whole current of Niagara, with all the power of its mighty rush, cannot influence a grain of iron on its banks, or deflect the needle of the most sensitive galvanometer.

Electricity is measured, by measuring *differences in these effects*. We may note differences in the heat caused in the conductor, and say that that current is the stronger of two which produces the higher elevation of temperature. We may decompose liquids, and determine the relative strength of currents by differences in quantities of gas evolved or metal deposited. We may note the deflections of magnets brought near to the conductor, and find the relation between deflections over given angles and currents of varying strength.

In order to measure anything, it is of course absolutely necessary to have some standard of measurement —or, in other words, some units—in which we can express conditions and differences of conditions. We measure water, for example, by quarts, gallons, &c., or we may speak of it as delivered at the rate of so many gallons per minute, or as under a certain pressure or head. For the measurement of electricity there are various established units, of which, however, we shall here refer to the so-called "practical units," noting others briefly further on.

The electrical effect which, by reason of its constancy, is usually taken as the basis of a system, is that known as electrolysis, or the loosening of the bonds of chemical affinity which unite the atoms in the molecules of a conducting liquid, by the agency of the electrical current caused to traverse it. In this way water is resolved into its constituent gases, hydrogen and oxygen, which may be separately collected; a. d solutions of the metallic salts are caused to deposit the metals contained in them. The unit quantity of electricity is that which will set free ·000162 grain of hydrogen from water, or ·005084 grain of copper, or ·005232 grain of zinc from a solution of either metal.

It will be observed that time is not here taken into account. We say simply that when ·000162 grain of hydrogen is released, then we will call the quantity of electricity which has acted to produce this result one *coulomb*, just as we might say, and in fact do say, that when a vessel of a certain capacity is filled with water, the amount of water present shall be called one quart. Now our quart vessel might be filled in a minute or an hour, and we should express the fact by saying that the water is delivered into the vessel at the rate of a quart per minute, or per hour, as the case might be.

In electrical parlance, we have a single word to express this rate, namely, *ampere*. When the coulomb of electricity flows past any section of the circuit—or, what is the same thing, when ·000162 grain of hydrogen is liberated in one second—then we say that the current is of unit strength, that is, a strength of one ampere. If twice the above amount of hydrogen were liberated in the same time, the current would have a strength of two amperes; if half the amount were liberated in the same time, the current would have a strength of half an ampere, and so on.

If we were dealing with water flowing at so many gallons per minute, for example, we should find that this flow was dependent upon two factors: first, the pressure which impels the water along its channel; and second, the resistance offered by the channel, or any obstruction in it, to the passage of the water. We should find, further, that, other things being equal, the greater the pressure the more water would flow. On the other hand, everything else being equal, the greater the resistance the less the amount of water which would pass. The electrical flow (supposed) bears a close analogy to the water flow, and the expression of this constitutes the great fundamental law of the electrical current. Its strength depends directly upon the electrical pressure. The greater the electrical pressure the greater the strength, the greater the number of amperes, or the number of coulombs per second. On the other hand, the greater the resistance offered to electrical flow, the less the number of amperes, or coulombs per second.

But what is electrical pressure, and what resists electricity? Water pressure may of course be caused by gravity or a force pump, but gravity cannot influence electricity, which is totally incorporeal, and has no weight; besides, it is not clear how a weightless incorporeal entity is to be pumped. Electrical pressure is more commonly called electro-motive force, usually abbreviated to E M F. Water will flow from a high place to a lower one, gravity impelling it. It will seek its own level. So electricity will flow from a place of high potential to a place of low potential, that is, from a point where its capacity for doing work is greater, to one where its capacity for doing work is less, provided a conducting channel—a metal wire, for example—be provided for it. Electro-motive force is due to the difference of potential, and determines the flow. Difference of potential is caused by every electrical generator, whether galvanic cell, dynamo-electric machine, or any other apparatus seemingly producing electricity.

Some substances will conduct electricity better than others; some will practically not conduct electricity at all. A rod of glass is a non-conductor, a rod of metal is an excellent conductor. To say that a body will not conduct at all is the same thing as to say that it opposes an infinite resistance to the current. If it could conduct perfectly, it would offer no resistance. Between infinite resistance and no resistance there is of course every degree of more or less resistance.

So here are two factors upon which the strength of the current depends, and for each of which we need some standard of measurement. When two electrical conductors of different potential are brought together, one will disturb the electricity of the other, and an attractive force will be set up, which will cause the bodies to approach one another. Now the magnitude of this attractive force bears a certain definite relation to the difference of potential between the bodies, so that if we measure the force of the attraction—weigh it, so to speak—we can find out what the difference in potential is; and by taking, further, into consideration the distance between the bodies and their shapes and sizes, we can obtain an expression for the unit of potential difference, which has been arbitrarily called the *volt*. For all practical purposes, however, it is much simpler to regard the volt as representing the electrical pressure of the current yielded by some standard form of galvanic cell, usually the Daniell element; or to consider it as the difference of potentials which must be maintained at the ends of a wire of one *ohm* resistance, so that a current may pass through it.

The *ohm* is arbitrarily fixed as the resistance offered by a certain definite body at a certain temperature. A column of mercury at 0° Centigrade, one square millimetre in section, and 106 centimetres in length, offers exactly one ohm resistance. Ordinary iron telegraph wire has a resistance of from ten to fifteen ohms per mile. Or we may say that one ohm is the resistance which is overcome by a current having a strength of one ampere at an electrical pressure (or having a difference of potentials) of one volt.

It is not difficult now to perceive the relation of the three practical units—ampere, volt, and ohm. A current having an electrical pressure of one volt traversing a conductor of which the resistance is one ohm, has a strength of one ampere; or, to put this in the form of a simple ratio,

$$\text{C, or current strength} = \frac{\text{E, difference of potential or electrical pressure}}{\text{R, resistance}}$$

So that, if we know any two of the terms in the above statement, we can easily find the third. Thus, knowing the difference of potentials in volts, and the current strength in amperes, we have only to divide the former by the latter and we have the resistance in ohms; or, knowing the resistance in ohms, and the strength of the current in

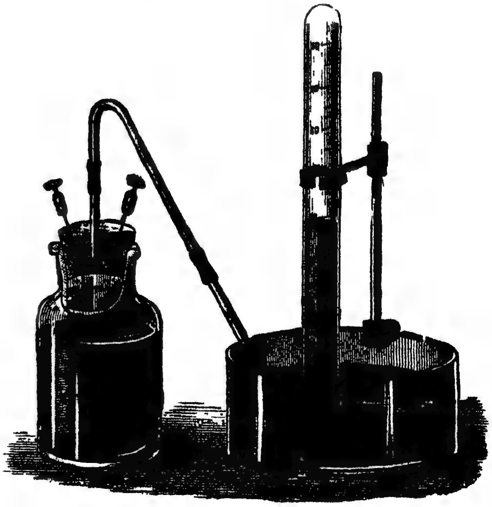

Fig. 1.—The Voltameter.

amperes, by multiplying these together we can determine what the corresponding pressure in volts must be. This however, convenient as it often is,

is simply expressing the relations of factors, and unless we can directly measure at least two of these we shall merely be speaking in what algebra calls terms of $x$ and $y$, without knowing what $x$ and $y$ themselves represent.

Let us start with the measurement of current strength. It has been said that a current of a strength of one ampere will liberate ·000162 grain of hydrogen from water in one second. This gives us at once a very simple and fairly accurate means of measuring strength directly. The apparatus used for the purpose is called a voltameter, and is illustrated in Fig. 1. The current enters the water from one of the plates suspended in the bottle, and passes off by the other plate, decomposing the water in its passage from one plate to the other. Hydrogen and oxygen are produced in the proportion of two volumes of hydrogen to one of oxygen, and the mingled gases are collected in a graduated tube. The proportion and weight of hydrogen being known, and the time being noted in which it was evolved, it remains simply to divide this weight in grains by ·000162 and we have the strength of the current in amperes. For practical purposes it is a simpler proceeding to cause the current to deposit metal from a metal salt solution for a given time, and then weigh the deposited metal.

While the foregoing method is the most direct way of measuring the strength of a current, it is practically of little value, because it requires great expenditure of time. In order to decompose one gramme of sulphuric acid a current of a strength of one ampere would require nearly three hours. Weaker currents, such as are used in telegraphy, might flow through the apparatus for days before any indication of their presence would appear. There are numerous other difficulties not necessary here to mention, the consequence of which is the substitution of the galvanometer for the voltameter for practical purposes, and the employment of the latter as a standard current meter, whereby the correlation of the effect produced in the galvanometer and the actual strength of the current may be experimentally ascertained by direct comparison.

When a current is passed through a conductor, and a magnetic needle is brought into proximity to that conductor, the effect of the passage of the current will be to cause the needle to set itself in a position transversely to the path of the current, and the direction in which the needle will turn will depend upon the direction of the current. Thus if the wire be represented at A B (Fig. 2), and placed over the needle (N S), then when the current circulates from B to A, the N end of the needle will

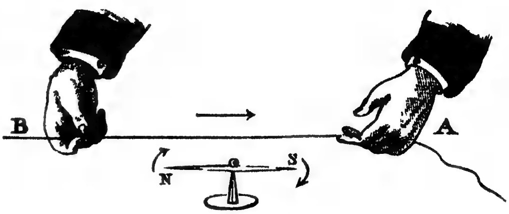


Fig. 2 —Œrsted's Experiment.

move to the right; when the current circulates from A to B, the N end of the needle will move to the left.

The movement of this needle clearly shows two things: first, the direction in which the current moves in the wire (apparently); and second, it may convey to us an idea of the strength of the current, inasmuch as there is a law connecting the magnitude of the deflection with the strength of the current which produces it. As a single wire might exert but very little perceptible effect, the influence of the current may be increased by augmenting the number of wires in proximity to the needle. A simple apparatus thus made for showing current direction, and for allowing of a rough estimate of the strength, is that shown in Fig. 3, which is commonly called a multiplier.

For practical use, however, galvanometers are made in a variety of forms, and dependent upon

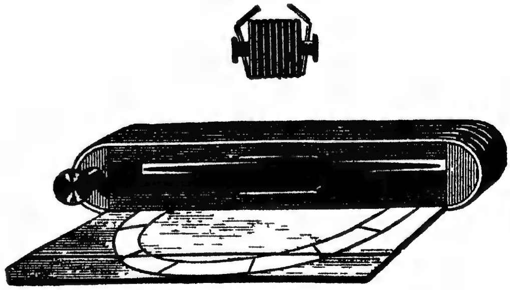

Fig. 3 —A Galvanic Multiplier.

different principles. They may measure the relative strength of currents as shown by different deflections produced; and also the absolute strength, or, in other words, the number of amperes required to produce some one deflection. So also they will measure electrical pressure in volts, the number of volts required to produce some one deflection being ascertained.

To measure very weak currents, and take very accurate readings, the instrument shown in Fig. 4

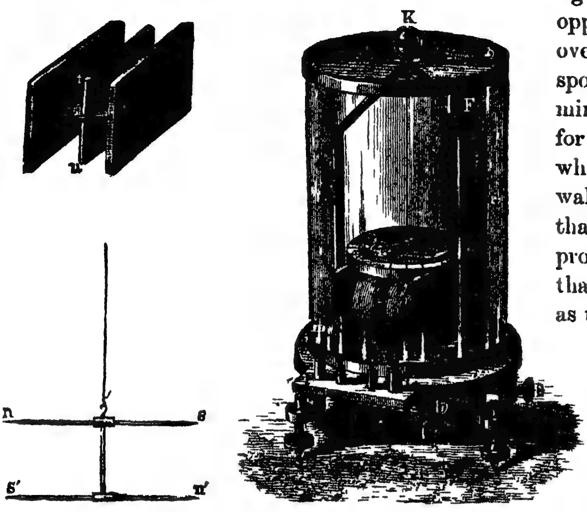


Fig. 4.—The Astatic Galvanometer.

is generally used. It has two coils that may be connected so that the same current goes round both in the same direction or in different directions, or the coils may be used separately. Two magnet needles are employed of equal strength and size, bound together, as shown in the figure, by a light wire, usually of aluminium. They are placed in reversed positions, so that the force urging one to set itself in the magnetic meridian is exactly balanced by the force that acts on the other. Hence the twin needles will remain in any position in which they are set, independently of the directive force of the earth's magnetism. When a current is sent through the wire coils, the needles move to the right or left over a graduated circle. When the deflections are small—that is, less than 10° or 12°—they are very nearly proportional to the strength of the currents passing. In the apparatus represented in Fig. 4 one of the coils has about 100 turns, the other 10,000. The four binding screws (P to O) are in connection with the ends of the two coils. The needle is hung from the metal support (E, F, G). The screw (K) serves to raise and lower the needles. The number of turns in the coils in an instrument of this class depends upon the purpose for which it is to be used, less turns being necessary when the circuit normally contains small resistance.

The greatest accuracy in measuring the deflection of a needle in a galvanometer is obtained by noting the position of a spot of light reflected from a mirror upon a lengthened scale. The beam of light becomes a pointer or index of no weight, and opposing no frictional resistance, and it will move over very considerable distances on the scale in response to very slight changes in the position of the mirror. Any one can demonstrate the operation for himself by the aid of a bit of looking-glass from which a ray of sunlight may be reflected upon the wall or ceiling of a room. It will be remarked that even imperceptible tremors of the hand will produce large movements of the bright spot, and that the extent of these movements will be greater, as the distance of the light image from the mirror surface is increased. In this way deflections of the galvanometer needle, scarcely possible otherwise to perceive, may be observed immensely magnified, and their extent accurately noted.

The general arrangement of the reflecting apparatus is shown in Fig. 5. Here *s* is the

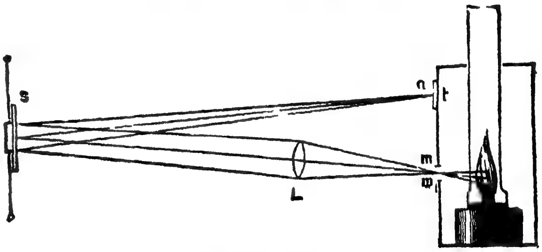


Fig. 5.—Reflecting Galvanometer.

mirror reflecting a ray of light from a lamp upon a scale, *t* (shown more in detail in Fig. 6), the double

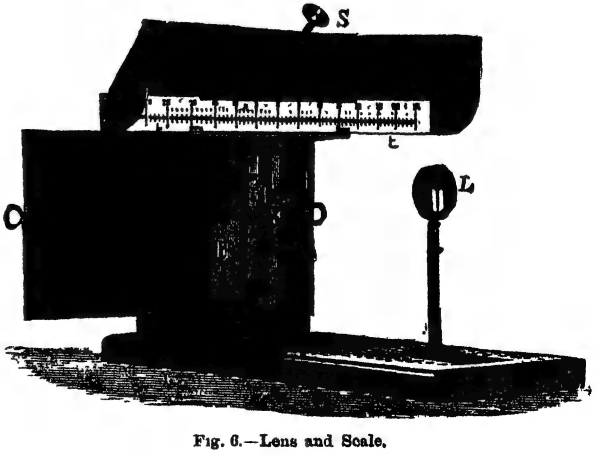


Fig. 6.—Lens and Scale.

convex lens L being for the purpose of making an image of the slit *m m* on the scale. The lamp is shut

up in a box, as shown in Fig. 5, so as to prevent a general illumination of the scale. The handle s (Fig. 6) works a rack and pinion for moving the scale horizontally, so as to bring the zero mark on the scale opposite the spot of light or image.

Galvanometers of the type above described are, as has been stated, extremely sensitive, and for other reasons not well suited to the measurement of the powerful currents used for industrial purposes. For this purpose galvanometers of special construction are employed, known as ampere-meters or ammeters, and voltmeters, accordingly as they are used to give direct readings in amperes or volts.

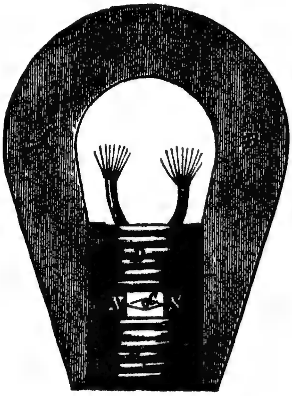

Fig. 7.—Ayrton and Perry's Ammeter.

The ammeter devised by Professors Ayrton and Perry is represented in Figs. 7 and 8. In this apparatus a very light magnetic needle, C, can move freely in the magnetic field formed by the

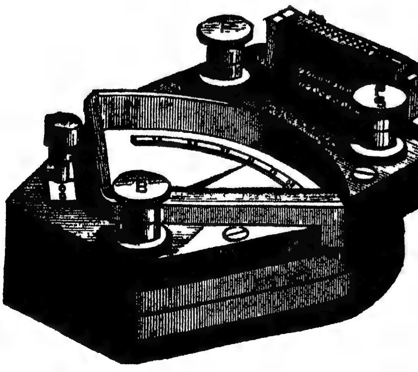

Fig. 8.—Ayrton and Perry's Ammeter.

armatures N and S of the magnet A B. The two coils D $D_1$ consist each of ten wires, and are so arranged that each deflection of the needle is directly proportional to the strength of the current. The object of the strong magnetic field is to reduce the influence of the earth's magnetism to a minimum. The same instrument is adapted to measure electromotive force in volts, by substituting for the wire coil of low resistance a coil of fine wire of high resistance, because with such a coil there is much less chance of the potential difference being altered by the current flow through the instrument itself.

For exact measurement of differences in potential, a very beautiful and accurate instrument, devised by Sir William Thomson, and known as the quadrant electrometer, may be employed. A light body connected with the inner coat of a Leyden jar, by which it is charged, hangs near two bodies, the electrical condition of which is to be tested. The difference in electrical condition is measured by the resultant attraction of the light body, which last is an aluminium needle carrying a small mirror, which serves to indicate the deflection by reflecting a beam of light upon a scale. The number of divisions which the spot of light traverses on a scale, measure the difference of potential.

For practical purposes, however, current galvanometers are employed to measure both the strength of the current and its pressure; the principal difference between the two types of instruments being, that the galvanometer is made so as to have in itself as small a resistance as possible when designed to measure strength; while, if it be intended to measure electrical pressure, its internal resistance is made as high as possible

We have now noted very briefly how two of the important factors, current strength and electromotive force or electrical pressure, are measured; and, as has been already stated, with this knowledge we can easily determine the resistance of the circuit by the aid of the simple ratio of current strength to electrical pressure and resistance, already explained. This, of course, is an indirect method. There are, however, various ways of measuring resistance directly, the simplest of these depending upon the comparison of the body the electrical resistance of which is to be determined, with a body the electrical resistance of which is known, or which can be adjusted as may be desired. One of the earliest instruments for accomplishing this object was the Rheostat, which consisted of a long German silver wire of known resistance coiled round a non-conducting core so that the coils were not in contact. One terminal of the current employed was connected with the end of the rheostat coil: and by a movable contact piece the other terminal might touch any one of the coils, and so embrace any given number of coils in the circuit. The rheostat is still

employed to some extent, but is mostly superseded by the more convenient "resistance-box," represented in Fig. 9.

Fig. 10 will make clear the principle of its construction. Two resistance coils are here shown, the ends of each coil (the resistance of which is

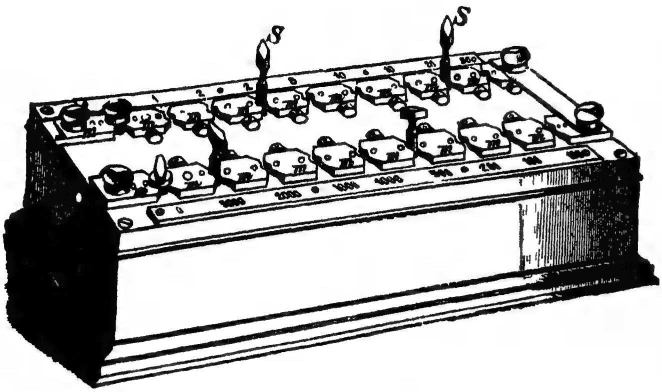


Fig. 9 —Resistance Box

previously accurately determined) being connected to the brass plates *m m*, which are divided from each other by a small air space. A semicircular opening is made in each plate so as to form seats for brass plugs, such as s. If now the current enters at one of the plates *m*, it will flow to the

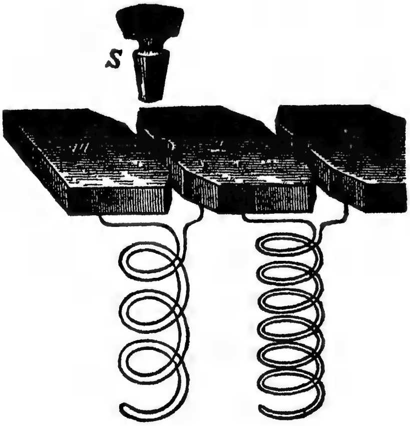


Fig. 10.—Resistance Coil and Plug

next adjacent plate *m* if the plug s is inserted between these plates; but if the plug is not in place, then the current is compelled to pass through the coil in flowing from plate to plate. A number of coils, each one of a different resistance, are arranged in the box shown in Fig. 9, and by the insertion or removal of the metal connecting-plugs the current may be made to flow through any or all of the coils, as desired, and in this way an accurately predetermined resistance may be interposed in its path.

Having thus provided a standard for comparison, we can proceed to measure the unknown resistance of any body.

This can be done in various ways, of which the simplest are by what is known as the substitution method, and by the aid of a very ingenious device invented by Professor Wheatstone, and hence termed the Wheatstone bridge. In the substitution method a complete circuit is made with a constant galvanic cell—a galvanometer and the wire, for example, the resistance of which is to be determined. The deflection of the galvanometer being noted, the wire to be measured is removed, and in its stead is substituted a resistance-box such as has already been described. Resistance is now adjusted until the needle of the galvanometer shows the same deflection as before. This resistance will be equal to the resistance of the wire under examination.

This method is not a very accurate one, and

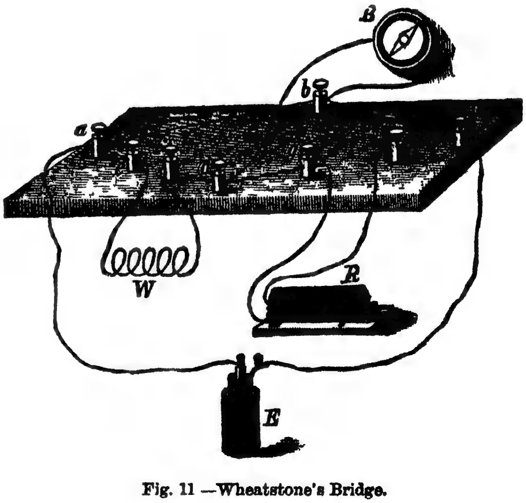


Fig. 11 —Wheatstone's Bridge.

in practice, some form of the Wheatstone bridge is far more generally employed. The simplest arrangement of the bridge is that represented in Fig. 11.

Four binding-posts (*a*, *b*, *c*, *d*) are here shown arranged upon a board. From *a* to *b* extends a wire,

and from $b$ to $c$ extends a wire. These wires are equal in length, and in the resistance which they respectively offer to the current. Between $c$ and $d$ are placed binding-posts, $g$ and $h$, for the convenient insertion in circuit of a resistance coil, R. Between $a$ and $d$ are placed binding-posts, $e$ and $f$, for convenience in connecting in circuit the wire W, for example, the resistance of which is to be measured. One pole of the galvanic cell E is connected to the binding-post $a$, the other pole to the binding-post $c$. One terminal of the coil of a galvanometer, B, is connected to the binding-post $d$, and the other to the binding-post $b$.

Suppose now the current to start from the battery and pass to the post $a$. From $a$ it has two roads open to it to $c$: one road from $a$ to $b$, and thence to $c$; and the other from $a$ to $d$, and thence to $c$. When the resistances of the wires $a$, $b$ and $b$, $c$ are to each other as all the resistances between $a$ and $d$ are to all the resistances between $c$ and $d$, then no current will pass through the galvanometer B; and this gives us a simple ratio as follows:—

$$\frac{\text{resistance of } a\ b}{\text{resistance of } b\ c} = \frac{\text{resistance of } a\ d}{\text{resistance of } d\ c}$$

from which we can easily calculate the resistance of $a$, $d$, when all the other three resistances are known. In practice, the resistances of $a\ b$ and $b\ c$ are fixed once for all. The resistance in the coil R is adjusted until the galvanometer shows no current, and then the conditions of the above ratio obtain, and the rest is a matter of simple arithmetic. Thus if $b\ c$ is ten ohms, and $d\ c$, including the coil, 100 ohms, and $a\ b$, fifteen ohms, the resistance of $a\ d$ is (15 multiplied by 100 and divided by 10) 150 ohms.

We have now outlined very briefly how the electric current is practically measured; its pressure, the resistance offered to it, and its strength being determined either directly or through their relations as indicated by Ohm's law. It is necessary still to illustrate how these measurements are directly utilised in determining what work the current does; for of course, no matter what the resultant effects may be—whether mechanical, chemical, thermal, or magnetic—the energy of the current is expended and work is done.

For example, let us first consider the heating effect. Here we need a heat unit. This is arbitrarily fixed as the amount of heat which will raise one gramme of water through one degree Centigrade of temperature. How many of such heat units will a given current generate? It has been determined that this last will depend upon the resistance offered to the current, upon the square of the strength of the current, and upon the time during which the current lasts. If, then, we measure the resistance and current strength, and note the time, we shall find that when a current of one ampere strength flows through a resistance of one ohm, it will develop in its conductor 0·24 heat unit per second. As another instance, suppose that it is to be desired to find the rate at which the current is doing work in an electric lamp. The strength of the current is first measured in amperes, then the electric pressure of the current in volts, these factors are multiplied together and divided by 746, and the result is the horse power used up in the lamp. Here we deal with electric *power*, and the unit is one ampere working through one volt, which is called one watt. One horse power is therefore 746 watts.

So far we have dealt, though very briefly, with so-called practical units—that is, with the standards of measurement most commonly employed in every-day work. There are, however, other units, known as "absolute units," which are based upon the fundamental quantities of length, mass, and time. That is, in order to realise them, we start simply with these three abstract quantities, in terms of which force, velocity, &c., may be expressed. As a unit of length, the centimetre, equal to 0·3937 inches, is chosen; the unit of mass is the gramme, or 15,432 grains, or the mass of one cubic centimetre of water at 4° Centigrade; the unit of time is the second. From these units we can derive others, as follows:—The unit of area is the square centimetre; of volume, the cubic centimetre; of velocity, that of a body moving at the rate of one centimetre per second; and of acceleration, an acceleration of one centimetre-per-second per second. It will be observed that all of these units are dependent on nothing but the three initial standards of length, mass, and time, which, of course, are arbitrarily chosen.

We can go on and build up, so to speak, still more derived units. The unit of force, for example, is that force which, acting for one second on a mass of one gramme, gives to it a velocity of one centimetre per second. As we could not well say all this whenever we might desire to express this unit, we call it one *dyne*. Here, then, is an expression for a force. If we act against this force, we must do work. If we should push a body through a distance of one centimetre against a force of one *dyne*, then we

should accomplish the unit amount of work, and that is called one *erg*.

Now, while all the foregoing has been devised for electrical uses, it has really no direct connection with electrical energy, any more than with any other form of energy. It remains, therefore, to indicate how electrical units are derived from their fundamental conceptions.

The first law of electro-statics is that electric charges of similar sign repel one another, but electric charges of opposite signs attract one another. If now we should suppose these two charges collected at points, the second law of electro-statics comes into effect; and this is, that the force exerted between two charges of electricity is directly proportional to their products, and inversely proportional to the distance between them. Here is a force, and an electrical force, to be measured. We have already found a standard of force measurement, the dyne, and with the aid of this we can at once reach a standard unit of electrical quantity, because we may define it as that quantity which, when placed at a distance of one centimetre from a similar and equal quantity, repels it with a force of one dyne.

Instead of considering the force exerted between two quantities of electricity, we may refer to the force exerted between two magnetic poles, and in this way we find that the unit magnetic pole is one of such a strength that, when placed at a distance of one centimetre from a similar pole of equal strength, it repels it with a force of one dyne. The result is that we have two systems of electrical units—one set based on the force exerted between two quantities of electricity, and the other upon the force exerted between two magnetic poles—and between the two systems there is a certain relation.

It is not practicable within available space to trace out the derivation of the units of potential and resistance from the above systems. It will suffice to say, however, that what are called the absolute units are inconveniently small for practical use. The volt equals $10^8$ absolute units, and the ohm $10^9$ absolute units. Consequently the ampere would represent a potential of one volt acting through one ohm or $10^{-1}$ of an absolute (electro-magnetic) unit of a current. But it is needless to go further into the details of a subject which bristles with technicalities, many of them of such recent invention as not yet to be completely incorporated into the accepted language of the science. It will suffice to add that the selection of measuring instruments, the modes of their use, not to mention the various "methods," involving often the highest orders of mathematics, largely depend upon individual experience and preferences. While the general principles involved remain of course the same, their application widely differs, in accordance with particular adaptations of electricity to practical uses. The reader will find that telegraph engineers prefer certain methods and instruments; electric-light engineers other apparatus and methods; and only amid the refinements of the well-equipped physical laboratory will attempts at measuring the wonderfully minute currents which influence telephonic transmission be attempted.

## THE RAINBOW.

By William Ackroyd,

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THAT which to the Romance races is *the arch in the heavens*, and to those of Teutonic descent the *rainbow*, has ever been a source of delight to all, and the theme of endless allusions by the poets. Neglecting the poetry, let us try and get at the philosophy of the "ethereal bow," as Thomson terms it. To that end, we will first glance at a scene which we have probably beheld hundreds of times before without noticing those features to which we shall now direct our attention. Before us stretches a broad landscape, diversified by hill and dale. Farm-houses are seen here and there, likewise patches of forest, and winding in and out a river pursues its sinuous course until it is lost to sight behind a distant hill. To the back of us is the sun, and before us dark clouds that portend rain. Presently, we can see in the distance that it is raining; and there now springs into view, as if by magic, a many-coloured bow, reaching into the heavens, and being lost imperceptibly on one side in a meadow, and on the other embosomed in trees. With more marked attention,

we see a second bow outside the first, and much fainter in appearance. The order of the colours is not the same in both, for in the inner or *primary* bow red is on the outside and violet on the inside, whereas in the *secondary* and fainter bow red is on the inside and violet on the outside.

Let us observe the phenomenon under other conditions. We are now by the side of a fountain whose jets of water are thrown high into the air, and there scattered into a thousand particles, which sparkle in the sunbeams. Walking leisurely around the basin, we notice that in one position, and in that only, we can see portions of a rainbow. Our back is turned to the sun, and our face towards the water-drops.

We may infer, then, from these separate observations, that there are certain conditions essential to the production of one of these coloured bows; first, we must have rain, whether it be the outpouring of a cloud, or the spray from a fountain; secondly, the light of the sun must fall on this rain when the observer is in a certain position at some point between the sun and the shower; and, thirdly, we must face the shower. To get at the explanation of the rainbow, we have therefore to consider the action of rain-drops on light; and at the outset we shall have to inquire into the nature of the latter.

Physiologists tell us, and it admits of easy proof, that all our feelings or sensations are produced by an agitation of the nerves of the sensory organs. This agitation is transmitted along the nerves to the brain, and there awakes in us a state of consciousness. Thus, when air is suddenly and greatly disturbed, it beats against the drum of the ear, and certain little stones within that organ are ultimately set in motion. The ear-nerves are agitated, and the disturbance being conveyed to the brain, there produces the sensation of sound.

Similarly it sometimes happens that a fall from a height is accompanied by the sensation of a flash of light; and the appearance is well known to pugnacious youth, who often, in their encounters, upon getting a smart blow in the region of the eyes, momentarily imagine sparks of fire have danced before them, and speak of the phenomenon as "fire" being struck in their eyes. We with less bellicose tendencies may assure ourselves of the fact that the sensation of light can be produced by pressing a finger against one side of the ball of the eye moderately hard, and working it up and down. Although the eye is closed, we see a pale-white image which moves in a contrary direction to that of the finger, and it is evident that somehow or other we have agitated that large nerve which leads from the back of the eye (*retina*) to the brain, and is known as the *optic nerve* (p. 165).

Bearing these facts in mind, it is possible to frame some hypothesis of the nature of light, and we shall now in a few short paragraphs present to the reader that which is the outcome of ages of labour; for the progress of discovery is necessarily a ziz-zag one, and were we to minutely describe those wanderings of the mind, first to the right and then to the left, in the development of this branch of science, we should take up much more space than that allotted to us.

On the table before me stands a lamp burning brightly. Through the instrumentality of the parts of the eye it has produced in me the sensation of light, and the question arises, By what means has the back of the eye or retina been agitated to give one this feeling? Using our common sense, we know that motion, to be sent to a distance, must be communicated from one body to another. When we see the last of a long train of previously stationary carriages give a start, we know that the locomotive backed up against the first one, and that the first was thus thrust against the second, and so on, until the last carriage had been affected. A piece of cork floats on a still pond, and, being disturbed by no breath of air, is perfectly stationary. We throw a stone into the water some distance from the cork. Anon, the cork dances up and down, being now on the crest of a wave, and a second after in a hollow. Motion has plainly been given to the cork, and in the following manner:—At the spot where the stone sank, the water was disturbed, pushed down, and thrust away on every side. The wave-motion then commenced was transferred from one water-particle to another, and in the course of this transference the cork was passed. Plainly, if the water supporting the cork had been invisible, the motion of the latter up and down would have been sufficient evidence of the transmission of force from the stone to the cork, and therefore of the existence of the water. To draw an analogy: The flame of the lamp before me consists of atoms of carbon, hydrogen, and oxygen dashing about in the wildest manner imaginable, but on account of their excessive minuteness this fact has only been made out by a long course of patient research. This motion of the atoms in the flame has been transmitted in some way to the back of the eye, and thence the disturbance has been sent along the optic nerve to the brain

Now about the medium which transmits the motion, although invisible, we may readily ascertain a few important particulars. Upon interposing a piece of plate-glass between the eye and the lamp, I still see the flame, whence one may infer that the motion has been transferred *through* the glass—or, to be more exact, that the medium which transmits the motion exists among the particles of the glass. It is hardly surprising then to find that this medium likewise exists in the most perfect empty space that was ever made; for light can be sent across such a vacuum. This remarkable medium is known to scientific men as the *luminiferous ether.* Besides existing in what one would call empty space, and even in solid bodies, it has some other qualities that are very striking; and one of these is the quickness with which it transmits motion. If a bonfire were lit 186,000 miles away, we should see it exactly one second after: in other words, the impulse travels in ether at the enormous rate of 186,000 miles per second. We can form only a very inadequate idea of this great speed, even when we contrast it with other great velocities. Often when on one side of a valley have I seen a quarryman lift his mall and give a swinging blow to a stone. Between the fall of the hammer and the report reaching me there was a perceptible lapse of time—somewhere about five seconds (p. 125). The quarry was a mile away. Whilst sound was travelling this distance, light would have traversed 930,000 miles!

Such a rate of motion for all terrestrial distances would seem instantaneous, and it was not until the right construction was put upon a remarkable astronomical phenomenon that light was discovered to require time to travel through interstellar space. If the reader be the fortunate possessor of a good telescope, upon turning it towards Jupiter he will see that this planet is accompanied by moons which look like small dots of light. At regular intervals they enter Jupiter's shadow and are eclipsed. Confining our attention to the first moon, we should find that the interval between two eclipses is about 42 hrs. 28 mins. and 36 secs., and it would be possible to predict the time at which any eclipse would take place in the future, for it requires only a simple matter of multipliction; thus the ninety-ninth eclipse from now ought to take place in 99 times 42 hrs. 28 mins. 36 secs. In this way Roemer, a Danish astronomer, argued, but he found that his observations did not agree with his calculations, for when the earth was on the side of its orbit *farthest away* from Jupiter, the eclipses were found to be about 16 mins. behind the time calculated at the point nearest to this planet. It struck Roemer that this retardation might possibly be owing to the fact of light taking about 16 mins. to travel across the earth's orbit, and that if such were the case, it ought to follow that as the earth gradually neared Jupiter again, the apparent error should grow less and less. Roemer found this to be the case. It was an easy step now to calculate the speed of light, for it was only necessary to divide the diameter of the earth's orbit in miles, by the number of seconds required to pass over it. Since Roemer's time the rate at which light travels has several times been ascertained in quite different ways, and the results have been sufficiently near to his to make one firmly believe that the Danish philosopher's inference and subsequent calculations were correct.

Light travels in straight lines. On a dark and misty night the beams from a policeman's "bull's-eye" lamp may be readily seen to take a perfectly straight path; and virtually the same experiment forms one of the usual stock of our lecture devices to illustrate this point. Under ordinary circumstances, a room is full of dust-particles which the eye cannot see, but if the light of an electric lamp be sent across them when the room is darkened, the scattering of the light from these particles readily reveals their presence, and they also serve to show, like the mist and smoke-particles, that light travels in straight lines.

There are many points of resemblance between the motion of a water-wave and that of an ethereal impulse. One of these may be conveniently studied here. The only instrument we require is half a circle of paper graduated into degrees (Fig. 1),

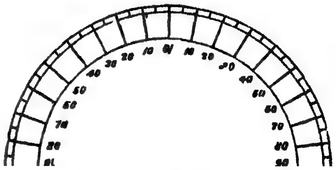

Fig. 1.—Scale wherewith to measure Angles.

and having procured this we shall then be prepared to institute a few comparisons.

The reader may probably have noticed the commotion which is made in the water when a steamer passes up a river. On each side of it a long wave is produced, which moves towards the shore, and the most noticeable feature is that when this wave has reached the embankment it is sent back in a

slanting direction opposite to that in which it came. Suppose (Fig. 2) the steamer is moving in the direction of the arrow at $a$, the motion of the paddles or of the screw sends a wave in the direction $b$ $c$, which is then sent back in the

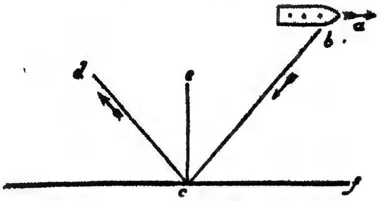


Fig. 2.—Reflection of Wave-Motion.

direction $c$ $d$. Now, if from the point $c$ we draw a line ($c$ $e$) at right angles to $c$ $f$, we shall find by the use of our paper scale that the angle $b$ $c$ $e$ is equal to the angle $e$ $c$ $d$. If we agree to call the angle $b$ $c$ $e$ the angle of *incidence*, and the angle $e$ $c$ $d$ the angle of *reflection*, then we may assert of wave-motion that *the angle of incidence is equal to the angle of reflection.* This applies to that particular kind of ethereal wave-motion which we call light. Innumerable proofs may be given of this; we shall content ourselves with giving one or two. Suppose we had a thin and straight piece of wood fixed by means of wax on the face of a looking-glass (Fig. 3), and at right angles to it. Then upon bringing the mirror in front of the beams from the bull's-eye lamp, the mist* would readily reveal the direction of the reflected light, and the eye would at once perceive that the angle made by the upright piece of wood with the incident beams $b$ $c$, is equal to that which it makes with the reflected bundle $c$ $d$, and this could be proved to the satisfaction of the most scrupulous by means of the graduated paper scale.

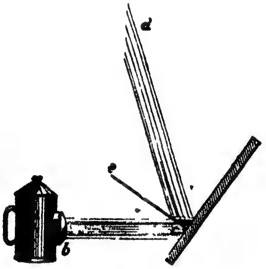


Fig. 3.—The Angle of Incidence is equal to the Angle of Reflection.

This law of the equality of the angles of incident and reflected rays will make plain many things which before seemed strange. Prop up a looking-glass on the table. Lay now a sheet of paper in front, and place a small piece of adhesive paper on the lower portion of the mirror. A button ($b$) placed on the extreme left will be seen in the mirror on bringing the eye to the right. Move the eye until the images of the button ($b$) and the label $c$ (Fig. 4) are in the same line, and place a second button in this line on the right-hand side. Now upon drawing three straight lines upon the paper, one from the label at right angles to the glass, and two from the buttons towards the label's image, it will be found that the two angles thus formed are equal to each other—*i.e.*, that the angle $b$ $c$ $e$ is equal to the angle $e$ $c$ $d$. It is necessary to say here that things which, like the buttons, do not give out their own light, are seen by borrowed or reflected light. A lamp shines and gives out its own light, but all other objects in the room send back this light, and are thus made visible. In our present experiment, the daylight reflected from the left-hand button strikes the glass at the part where the image of the label is,

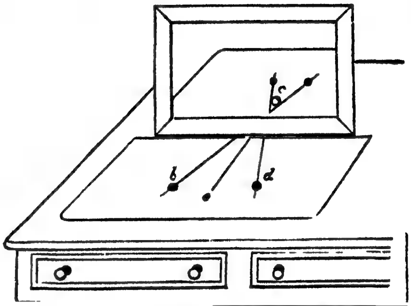


Fig 4.—How we see ourselves in a Mirror.

and it is necessary, if we want to see the button in this position, to bring the eye until the angle of incidence is equal to the angle of reflection. Hence it is that when viewing ourselves in a mirror we must be directly opposite to it, for if we move to the right or left we can no longer see ourselves reflected, but may be seen by an observer placed to the left or right of the glass, as the case may be.

We have so far dealt with the movements of light in one medium; but ether pervades nearly all things, and laves the ultimate particles of which they consist, and these particles in their turn materially influence ethereal motion. Light, for example, travels much slower in glass than it does in air, and when motion is transmitted from the ether in air to that which pervades glass—or, to use the customary phraseology, when a ray of light passes from air into glass, such is the nature of the ether-waves that a twist is given to the direction of the ray at its point of entrance, and the straight path of the ray within the glass is not in the same line as that of the ray outside it. Such a breaking of the direction of a ray of light is called *refraction*,

* The smoke of brown paper will answer the same end.

and there are some very curious points connected with this phenomenon which I shall proceed to explain.

Put a small coin at the bottom of a basin (Fig. 5),

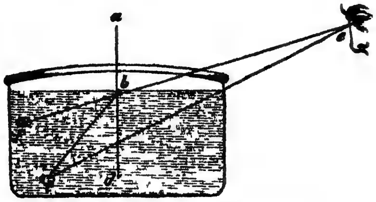

Fig. 5.—Refraction Experiment.

and place the eye so that the money is just hidden from sight by the side of the vessel. Now pour some water into the basin; the coin is brought into view. This is due to refraction. Let the accompanying figure represent the conditions of the experiment. The eye placed at *e* sees the coin apparently at *f* when the vessel is filled with water; join *e* and *f*. From *b* draw *b a* at right angles to the surface of the water, and produce the line *b a* to *d*. Although the coin seems to be at *f*, it is really at *c*; join *c b*. *a b e* is the angle of incidence, and *c b d* is called the *angle of refraction*. This is what has happened. The borrowed light proceeding from *c* in the direction *c b*, has, immediately upon entering the air, taken a fresh direction, *b e*; and as our experience leads us to suppose that objects rest somewhere in the direction of the rays which apparently proceed from them to the eye, the mind naturally judges the position of the coin to be at *f*. The apparent bending of an oar, when dipped into the water, is due to the same cause.

Procure one of those three-sided glass pendants which ornament chandeliers, and look through it at various objects. Everything seems displaced. This, the reader will now readily understand, is due to refraction; but, in addition, objects are beautifully fringed with colours. The latter phenomenon is likewise due to refraction, and may be best explained by describing a famous experiment, the true significance of which was first made out by Newton (Fig. 6). Through a round hole in a shutter, a ray of light (S) from the sun passes into a dark room in the direction A K; when, however, a prism of glass (P) is placed in its path, the bundle of rays are bent out of their course, and cast on the wall H I, there exhibiting the seven colours of the rainbow—red, orange, yellow, green, blue, indigo, and violet. By a critical examination of this experiment, one readily sees, first, that the light has been refracted in its passage through the prism; and, secondly, assuming the light to have been of a compound nature before entering the prism, we see that, of its constituents, red is least refracted, and violet most so. Hence, when we before examined objects with the prism, they appeared fringed with colours, because the light coming from them was split up in passing through the prism-shaped pendant to the eye.

Fig. 6.—Breaking up of a Ray of White Light.

By taking a second prism, and arranging it as in Fig. 7, the light, which before was split up, is now recombined, and the emerging ray E consists of white light. These experiments may be readily performed by the reader, and as diagrams convey but a faint conception of these phenomena, we would strongly advise him to repeat them.

Fig. 7.—Recombination of the Constituents of White Light.

We may now turn to investigate the influence of rain-drops on light; but seeing from the foregoing experiments the importance of shape in this action, we must first inquire into the form of a rain-drop.

We need not go far to ascertain this. It has just been raining, and a single glance outside shows one that a drop of water has a tendency to take the form of a globule, perfectly round. I see this in the drops hanging outside the casement, and suspended from the tips of the green leaves, the little balls of water, ever on the point of falling, acquiring a more and more spherical form, until they drop, and in mid-air attain to that perfection of rotundity which we call a sphere. This, however, only half satisfies us, and we determine to watch the falling rain-drops in the next shower. We try to do so, and are defeated. They fall so fast that the eye cannot follow them, and instead of spherules, they seem like streaks of rain. The artist catches this

idea well in representing a shower of rain by a series of parallel lines.

This is what has happened: The light from a rain-drop (Fig. 8), when at *a*, produces an impres-


Fig 8.—Rain Shower, illustrative of the Persistence of Impressions

sion on the retina, which lasts for about $\frac{1}{8}$th of a second; hence, long before the impression has died away, there are other images produced, continuous with the first, for the drop is quickly falling, and the continuity of these impressions gives the idea of a line of rain. This phenomenon, known as the *persistence of impressions*, is dealt with minutely in another paper.*

It is therefore useless to watch the falling rain-drops. Sometimes, however, they are frozen in their passage hitherward by passing through a stratum of very cold air, and in the hailstone we are presented with that form which we sought in vain to discern in the falling spherule. Tyndall has seen hail fall among the Alps in which each stone was perfectly round, the rain-drops having solidified in their descent. And, indeed, it would seem to be a general law that small portions of liquid should take this spherical form in virtue of those forces which bind their particles together when they are falling under the influence of gravity. In applied science we have a good example of it in the manufacture of small shot or pellets. Ladles of a peculiar form are filled with molten lead, into which a little arsenic has been put, and the metal in this fluid condition is sprinkled from a great height into a well of water. Drops are formed, which in their fall become partially cooled, and, solidifying in their descent, are perfectly round. The experiment is in every way analogous to the production of hailstones; and from these considerations we may safely say that a rain-drop is spherical. It remains for us to ascertain how such a sphere of water affects light. We propose to do so in an exceedingly simple manner.

Take a flask, and fill it with water. It must be of plain glass, as with a cut and ornamented decanter prismatic effects are introduced, which confuse the observer. Let such a flask of water represent a rain-drop, and take a lamp to represent the sun. Now place the flask at the back left-hand corner of the table, and put the lamp at the front left-hand corner. With the eye on the right-hand side of the lamp one may now see two images of the latter on the front surface of the flask, and two images on its back surface. We shall only concern ourselves with the brighter of the two images reflected from the back of the flask. Move the eye further to the right; then, just before we lose sight of the image, we shall see that it is beautifully coloured red on the left-hand, and blue to violet on the right-hand side. The light from the lamp is falling on all parts of the flask, and it is therefore necessary to find out where the light enters which produces the image we are observing. Prop up a book on the left-hand side of the flask, so as to intercept the light falling on a very small portion of that side of it. Upon placing the eye in the old position, we can no longer see the image. Hence the light enters the left-hand side of the flask, and comes out at the right-hand side, as it is there we see the image. In its passage it has been slightly affected, as the image is red on one side and violet on the other; the flask full of water has acted upon the light just like a prism of glass. The very spots where it enters and emerges may be ascertained by repeated trials with adhesive paper of this shape , which just admits the light forming the image to pass through. There is only one reflection at the back of the flask, and the precise position of this part is easily shown to be midway between the points of entrance and emergence of the rays. We are therefore now in a position to make a drawing, representing the flask by a circle, and the lamp-beams by straight lines (Fig. 9).

Let A B C stand for our flask in section. The rays from the lamp L proceed in the direction L A, and are bent within the flask into the direction A B; from B the image is internally reflected in the direction B C, and the emergent rays proceed from C to the eye placed at E. From E draw E F parallel to L A. Now if we were to move the flask and the lamp to our right-hand side to the positions given by the dotted lines, all the while keeping our eye in the

* Optical Illusions, p. 164.

same position, then we should find the same appearance as before, only that the coloured fringe of the image is apparently reversed, red being now on the right-hand side of it, while violet is on the left. Conceive of a number of such flasks being arranged in an arch, such that the coloured rays proceeding from each to the eye would make an angle with the line E F equal to C E F, which the reader may readily ascertain is about 42°, then we should have a coloured bow of lamp-images, with the red portion on the outside and the violet on the inside. The primary rainbow is formed exactly in the same manner.

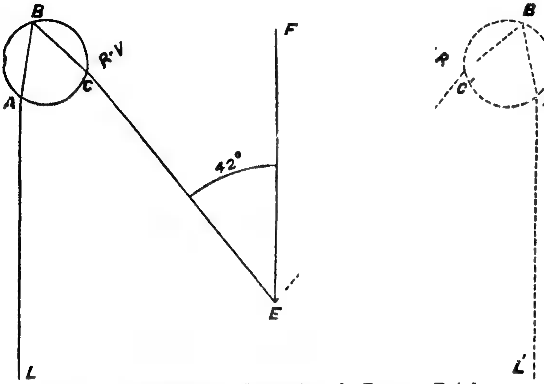


Fig. 9.—Illustrates the Formation of a Primary Rainbow

Heavenly bodies, like the sun and moon, are so far distant that their rays fall on all objects within the bounds of the horizon in a sensibly parallel direction; hence it is that, howsoever fast a youngster may run in the endeavour to outstrip the moon, this luminary seems to keep pace with him on the tops of the neighbouring hills. The reader will therefore see that all the rays which enter the rain-drops are parallel to each other, and that if the eye be placed at a proper angle to certain of the emergent rays, as in our experiment, then a bow will be seen in the air consisting of seven colours, with red on the outside and violet on the inside; and this bow will be formed of an infinite number of overlapping images of the sun.

The secondary rainbow is formed by rays reaching the eye which have been twice reflected within the drop. Such a drop is represented in Fig. 10, and the reader will now, after the example we have given, succeed in ascertaining the similar effect when the flask and a lamp are employed. The points to make out are: (1) The disposition of the coloured fringes, in this case the opposite of that which obtains in a primary bow; and (2) the angle (50° to 54°) which the emergent rays make with a line drawn from the eye parallel to the lamp-beams falling on the flask—*i.e.*, the angle D E F.

The time of day at which a rainbow appears is generally regarded by farmers, shepherds, and others accustomed to out-door work, as a weather-sign; thus, if it appear in the morning it is looked upon as the precursor of wet and stormy weather, but if it appear in the evening, then it is thought to precede dry and fine weather; hence the well-known doggerel:—

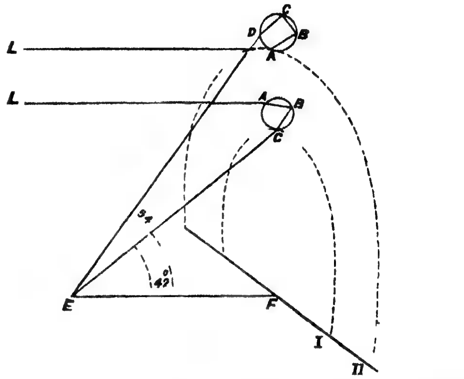


Fig 10.—Relative Positions of Primary (I) and Secondary (II) Bows.

> "A rainbow in the morning
> Is the shepherd's warning;
> But the rainbow at night
> Is the shepherd's delight."

Meteorologists tell us that there is some truth in this popular notion, and the reasons they give are these: A rainbow in the morning is seen in the west when the east is clear. It is indicative of the advance of the rain-cloud towards the observer, and, moreover, from the time at which it happens—morning—it points to the increasing moisture of the atmosphere. Wet and stormy weather is the natural sequence of such a conjuncture of circumstances. On the other hand, when a rainbow is seen in the evening, we have a reversal of these circumstances, for the bow appears in the east when the west is clear; the rain-clouds are receding from the observer, and the atmosphere is becoming drier. Fine weather necessarily follows.

Lunar rainbows are occasionally seen, but as the moon shines with light borrowed from the sun, there is nothing remarkable in one of these bows. They are formed in exactly the same way, and present the very same features as those we have already described.

Can a rainbow be reflected from a sheet of water? This is a question which has often been discussed,

and is all the more interesting because of the battles that have been fought concerning it. I propose to deal with it in a practical manner, and shall therefore describe a simple little experiment I have devised for that purpose.

We require a glass flask full of water, a lamp as before (L), and, in addition, a looking glass (Fig. 11).

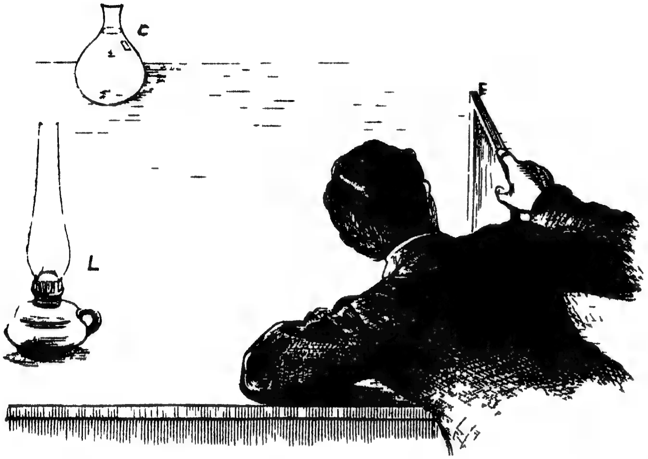


Fig 11.—An Experiment to illustrate the Reflection of a Rainbow.

Now dispose the flask and the lamp as represented in Fig 9, only place the mirror at E instead of the eye, and let its polished face be turned towards the lamp and glass. Stick a small piece of paper on that side of the flask at which the coloured image appears. Upon looking in the mirror so as to catch the picture of the flask at the proper angle, several intensely coloured images of the flame will be seen under the labelled portion. The manner of making this experiment is shown in Fig. 11, where the eye of the observer is so placed as to intercept the coloured image of the flame reflected from the mirror at E. Whilst in this position, turn the eye away from the mirror without altering the position of the head, and, moreover, turn the eye towards

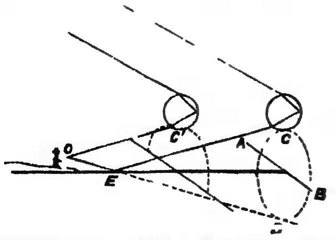


Fig. 12.—Illustrative of the Reflection of a Rainbow

the portion of the flask under the paper; *no coloured image can be seen.* This shows that when we are so placed as to see the coloured image reflected from the mirror we are not in a position for seeing it on the flask itself.

Let us now put our result in the shape of a diagram, so that we may be the better able to see what it teaches us.

The observer being placed at O (Fig. 12), in looking into Nature's mirror, a still sheet of water, sees a rainbow (A D B), but does not observe a rainbow in the air corresponding to it. For the drop C sends its coloured light to E, and thence to the eye just as in our flask experiment, and consequently a rainbow is seen in the water, but none in the air, with its feet attached to those of the reflected bow. Since the shower is of some extent, it follows from what we have already learnt that those drops nearer to the observer than C—say, for example, all similarly situated as C′—whose emergent coloured light enters the eye directly, will form a rainbow in the air which will be visible.

It has been observed that when a rainbow is seen, and another at the same time reflected from water, the feet of the latter appear within those of the former, although the order of the colours is the same in both—*i.e.*, red on the outside, and violet on the inside. This peculiarity has been seen by Mr. Crookes and other observers. Still, the phenomenon of reflected rainbows is an exceedingly rare one, there being so seldom the requisite combination of conditions to produce them—viz., such as a bright bow, an observer in the neighbourhood of a suitable piece of water, and the water tranquil enough to reflect the light. We have an instance on record where the flat wet sands of the sea-shore acted as a mirror, producing a reflected rainbow almost perfect in form and colour. The watery surface of the sand behaved almost like a looking-glass. The observer was Prof. Stanley Jevons, who had just been writing an account of a rainbow he had seen reflected in the Hardanger Fiord some two years before.

Sir David Brewster, in his "Treatise on Optics," describes a remarkable rainbow which was seen by Dr. Halley in 1698 Halley was walking on the walls of Chester, by the side of the river Dee, and saw the usual primary and secondary bows, and besides these a third, which, springing from the feet of the primary, extended up above the latter, the top of its bend coinciding with the summit of the secondary bow. The order of the colours in

this third bow was the same as in the primary; hence, where the secondary and the tertiary bows overlapped, there was portion of a silvery arch, for here there was a recomposition of the colours which constitute white light.

Since that time this rare phenomenon has often been seen, and it is noteworthy that the sun has generally been near the horizon, and the observer has had a sheet of water to the back of him. Hence it is thought that such nonconcentric bows are produced by light which has first been reflected from the water's surface before striking the rain-drops. Professor Tait* describes part of one seen at St. Andrews, in September, 1874. Its incompleteness was due to the fact of the observers being stationed considerably south of the estuary of the Eden, as from the latter the light was presumably reflected.

With a brilliant sun, and rain-drops of about $\frac{1}{76}$th of an inch in diameter, what are called *supernumerary bows* may occasionally be seen. They appear within the primary bow, and look like repetitions of it. They are formed of the same seven colours, in the same order, and seem continuous with the primary. Dr. Young has explained the formation of these *supernumeraries* on the principle of *interference*, a subject which will be fully dealt with in a future paper.

Since clouds are masses of vapour condensed into little drops of great minuteness, it comes within our province to give an account of the rainbow phenomena produced by them, and which are at times seen by mountaineers, balloonists, and others favourably circumstanced. On the 14th of February, 1873, M. Tissandier, the famous aëronaut, in making a balloon-ascent saw the following remarkable phenomena:—He and his party had passed through a mass of clouds, and reached some 164 feet beyond, when the shadow of the balloon was seen on the plain of mist below, and a circular rainbow was observed to surround the shadow of the car. The bow exhibited the usual seven colours, red, orange, yellow, green, blue, indigo, violet—the violet being on the inside, and the red on the outside of the circle. Fig. 14 is a sketch of what was seen at this stage. At the time the observation was made they were 4,430 feet above the level of the sea. The same phenomena have been repeatedly seen by travellers when on the tops of mountain peaks, with the sun overhead and a plain of clouds below.

On the occasion of which we have been speaking, M. Tissandier and company, when descending, a little later, towards the clouds, saw a couple of silver-coloured bows, elliptical in shape, and concentric with each other. *White rainbows* have been seen by other observers. Lieut.-Colonel Sykes †

Fig. 13.—Primary and Secondary Rainbows.

* *Nature*, vol. x, p. 437.

† "Philosophical Transactions," 1835, p. 135.

tells of one which he saw at Poonah during a fog. He says:—"I had mounted my horse shortly after daybreak in prosecution of my accustomed ride, and galloped a few miles towards the east. Suddenly I found myself emerge from the fog, which terminated abruptly in a wall some hundred feet high. Shortly after sunrise I turned my horse's head homewards, and was surprised to discover, in the mural termination of the fog, a perfect rainbow, defined in its outline, but destitute of prismatic colours." There is one other matter with which we must briefly deal. Light which has been reflected at a certain angle, seems almost or quite extinguished when viewed through certain crystals properly disposed. Thus, if the light reflected from the surface of a pond be examined through a crystal of Iceland Spar specially altered for the purpose, a Nicol's prism, then, in a certain position, the face of the pond will appear dark. Light with this peculiar property is, when reflected, said to be *polarised*. The light from a rainbow is polarised, and if the bow be examined by a crystal of the right material in a certain position, it will appear to vanish, coming into sight again as the crystal is turned round. Here we may illustrate the fact by observing the coloured image in the flask experiment with a Nicol's prism.

Fig. 14.—Circular Rainbow.

Turn down the flame so as not to give too intense a light. Matters being disposed as in Fig. 9, with the eye at E, and the flask at A B C, examine the coloured image at C through a Nicol's prism. Turn the Nicol slowly round on its axis, and it will be found that in certain positions the coloured image of the lamp nearly disappears. The light has plainly been partially polarised by passing through the filled glass globe. So it is in passing through spherules of water; and Biot in France, and Brewster in this country, discovered that a rainbow, when viewed through a crystal of tourmaline, or a Nicol, vanishes quite away from the sight, to reappear as the crystal is further turned on its axis. Such is a brief account of the remarkable appearances presented by the collective action of rain-drops on light, and henceforth our readers will see in a rainbow not only a simple rainbow and nothing more, but also a beautiful example of the unerring action of certain universal laws.

In reviewing what we have learnt, we must be careful to distinguish between fact and theory, for in investigating and interpreting natural phenomena, which is the aim of physical science, we can proceed only a certain length with perfect confidence. Thus, the rainbow is a complex phenomenon, and in the course of our investigation we have resolved it into its component phenomena of refraction and reflection. So far we are keeping on safe ground. When we come, however, a step further, and proceed to examine into the nature of reflection and refraction, we are obliged to assume the existence of a peculiar fluid which has been named *ether*. This ether may exist, or it may not. On the assumption that it does, we are able to explain numberless phenomena which otherwise would remain inexplicable, and this is the use of the hypothesis of an ether.

# FLYING REPTILES.

By H. Alleyne Nicholson, M.D., Sc.D., F.L.S.,

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Of all the powers possessed by one or other of the varied tribes of animals, there is none which has been more universally alike the admiration and the envy of the human race than that of flight. The philosopher has investigated the mechanism by which the bird or the insect is able to raise itself above the ground; and the capacity for traversing swiftly the vast and wandering fields of air has formed the theme of many a poet; while even the most commonplace of mankind is fain to gaze in wonder as he sees the hawk sailing in graceful circles, with wide-extended pinions, o'er his head, or as he watches the rapid evolutions of the untiring swallow. At the present day, the only animals which are endowed with the marvellous power of aërial locomotion, or of "flight" properly so called, are the birds, the insects, and the bats; some of the two former of these groups being, however, unable to support themselves in the air. Speaking generally, therefore, these three kinds of animals are the only ones which possess the power of "flight;" but the object of this paper is to show that there formerly existed animals belonging to a different class—namely, to the class of the Reptiles—which were likewise capable of flying; and in pursuit of this object we must explore the recesses of the past, and carefully examine some of the bones which geologists have exhumed from what are called the "Secondary Rocks."

While we have this definite object in view, and while we must leave to abler hands than ours the discussion of the laws and conditions under which flight is carried on, it is, nevertheless, necessary that we should just consider for a moment what we mean by the term "flight," for a great deal turns upon our accurately understanding this. Now, in the strict sense of the term, the power of flight is limited to the power of raising the body above the surface of the earth, of supporting it in the air, and of transporting it from place to place in the atmosphere. Accepting this definition, the only animals which now possess the power of "flight," as before said, are the birds, the insects, and the bats; and all of these fly by means of organs which are technically and popularly called "wings." These wings are organs which are differently constructed in each of the three groups of animals just mentioned, but which, in each case, are instruments adapted for beating the air by successive strokes, and moved by special muscles. All animals, then, which fly have "wings," in the above wide sense of the word. There are, however, many animals now existing, which are often spoken of as "flying" animals, though, in truth, they possess no power of "flight." The animals, for example, which are called

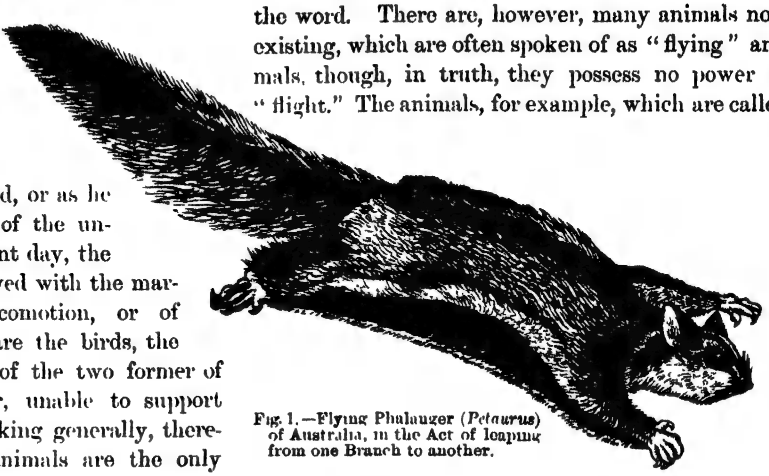


Fig. 1.—Flying Phalanger (*Petaurus*) of Australia, in the Act of leaping from one Branch to another.

"flying squirrels," the little "flying phalangers" of Australia (Fig. 1), and the "flying lemurs," of the Indian Archipelago, come under this head. They all possess, namely, more or less extensively developed folds of skin, which spring from the sides of the body and are attached to the fore and hind legs. By stretching out the legs, these lateral membranes are extended, and are thus rendered capable of acting as a support in the air, fulfilling precisely the same function as the "parachute" of the aeronaut. It is clear, however, that we have to deal here with structures very different from true "wings," and with a function not comparable with true "flight." The animals we have just alluded to have no power of raising their bodies from the ground by means of their "flying-membranes," nor can they beat the air with successive strokes of these organs. All that they can do is to raise themselves by climbing to a certain height, and then to launch themselves out into the air from the elevation thus attained to some lower point. In this procedure, the widely-extended lateral membranes serve to render their descent towards the earth a gradual and

slowly progressive one, and they are thus enabled to execute very prolonged and extensive leaps from tree to tree. It will be evident, however, that in no proper sense whatever can these animals be said to "fly."

Nor is it only among the quadrupeds that we find this power of darting through the air by means of lateral expansions. Thus, in the so-called "flying-fishes," the animal is able to dart out of its natural element into the less substantial air, and to perform leaps of great length, by means of the front pair of fins, which are of immense size, and which act exactly like the lateral folds of skin in the "flying squirrels." A still more singular example, and one bearing more directly on the subject now before us, is to be found in the extraordinary little lizards which are known as "flying dragons" (Fig. 2), and which are found in the forests of India and the Indian Archipelago. In these wonderful reptiles we have animals essentially similar to our ordinary lizards, but having the sides of the body furnished with wide folds of skin. These folds are supported by the hinder ribs, which run out straight from the back-bone, and which can be made to expand the "flying-membranes," in much the same way as the ribs of an umbrella enable us to open it. As in the case of the "flying squirrels," however, the "flying dragons" have no power of true "flight." They climb among the trees, and having reached a suitable elevation, they dart down upon the insects upon which they live, their so-called "wings" simply allowing them to accomplish leaps of comparatively enormous length without injury to themselves.

Fig. 2.—One of the "Flying Dragons" (*Draco*), viewed from above. (Of the natural Size.)

At the present day, no known reptile possesses the power of true flight; but geology teaches us that there existed in past time a large number of most remarkable reptiles, which could "fly," in as genuine a sense as the birds and the bats among existing animals. In other words, they possessed organs which may fairly be called "wings," since they could be made by appropriate muscles to beat the air with successive strokes, and to transport the body of their proprietor from place to place. The reptiles to which we refer are all extinct, not having even a near relation now in existence; and for reasons which we shall afterwards understand, they are known by the general name of "Pterodactyles." They are found in association with a very large number of other extraordinary types of reptiles, imbedded in the rocks which geologists call the "Secondary Rocks," so that they belong to what we may consider as the middle period of the earth's history. Though mostly found in a fragmentary condition—a skull in one place, an arm in another, and a leg in a third—we have, nevertheless, been able now to satisfactorily piece together the detached relics of these ancient reptiles, and it is worth our while to consider briefly their organisation and structure.

The ordinary forms of Pterodactyles (Fig. 3), as found in the fine-grained lithographic slates of Solenhofen, in Bavaria, or in the blue shales of the "Lias," at Lyme Regis, are comparatively small animals, mostly about the size of a pigeon or a raven. In the chalk, however, as we shall subsequently see, occur remains of gigantic members of this group, the dimensions of which greatly exceed those of the largest of living birds. Commencing with the head, we find the skull to be singularly bird like in its general form, and to be so constructed as to combine to a wonderful extent great strength along with the utmost lightness and economy of material. The jaws are long and beak-like, and would remind one very strongly of the bill of a bird, were it not for the fact that they are provided, throughout or over a portion of their length, with sharp conical teeth, sunk in distinct sockets. In the presence and characters of the teeth, the Pterodactyles resemble the crocodiles and alligators among the reptiles, and differ from all living birds, though a few fossil birds are also provided with teeth. There is also the curious fact that the huge Pterodactyles which are found in the chalk had no teeth at all, the jaws being apparently sheathed in horn, and thus resembling the beak of a bird. As some fossil birds, therefore, possess teeth, and as some Pterodactyles were toothless, it is evident that we cannot use the characters of the jaws as separating these two groups of animals. The only other point about the skull which need be noticed here, is that the "orbits"—that is to say, the bony chambers in

which the eyes were lodged, are of comparatively enormous size. From this it may be safely inferred that the Pterodactyles possessed greatly-developed organs of vision; and a strong probability is thus established that they were nocturnal animals, like our living bats, sleeping all day, and coming out in the twilight in search of food.

If we look to the characters of the back-bone in the Pterodactyles, we find that these curious animals present some features which would ally them with the birds, and others in which they approach the reptiles. Thus, the neck is long and slender, being apparently wholly wanting. The thumb, the forefinger, and the middle finger exhibit no special peculiarities, being of a size proportionate to the dimensions of the animal itself, and being furnished with sharp claws. The fourth finger, on the other hand, corresponding with our "ring-finger" (Fig. 3, *f*), is of immense length, sometimes nearly as long as the whole body, and it was not furnished with any claw.

Other peculiarities in the structure and conformation of the Pterodactyles will appear as we proceed; but we may now inquire how far the data

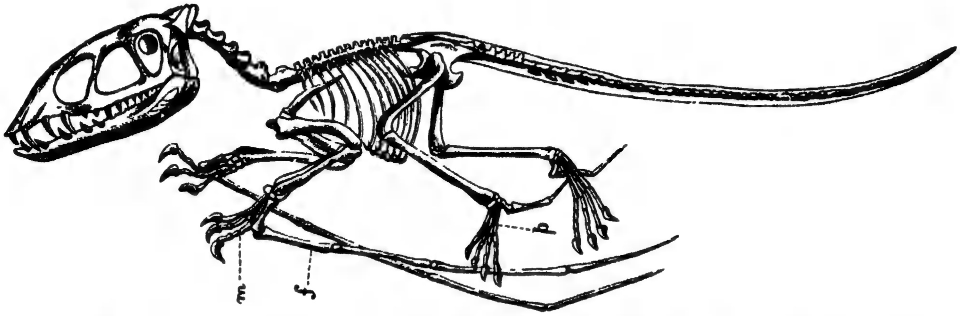


Fig. 3.—Skeleton of a Pterodactyle (*Dimorphodon macronyx*), greatly reduced in Size, and restored. (*After Owen.*) (*m*) Hand; (*f*) the greatly elongated Finger carrying the Flying-Membrane; (*p*) Foot.

closely resembling that of a bird, while there is in some cases a long and slender tail, such as we find in no living bird, though we are familiar with such a structure in a large number of existing reptiles. While the tail is often long (see Fig. 3), other Pterodactyles, however, had a quite rudimentary caudal appendage.

It is, however, in the structure of the limbs, and especially of the fore-limbs or arms, that the Pterodactyles show their most extraordinary peculiarities. The hind-legs of the Pterodactyles, though sometimes very feeble, are generally well developed, and are clearly suited for walking upon the ground, as well as for enabling their possessor to climb actively among the trees. Four of the toes carry sharp claws, which the animal doubtless used in grasping. The fifth toe, corresponding with our "little toe," was either rudimentary, or in other cases was longer than the other toes, and was employed in stretching and extending the "flying-membrane" which we shall afterwards see these animals to have possessed. The fore-limb or arm of the Pterodactyles consists essentially of the same bones as we should find in the fore-leg of a dog, or in the arm of a man; but there is a most marvellous modification of the structure of the hand (see Fig. 3, *m*). There are only four fingers to the hand, the "little finger" above given enable us to judge as to the habits and probable mode of life of these singular reptiles. We have seen, then, in the first place, that the feet are adapted for walking on the ground, or for climbing among trees; but we are forced at once to conclude that the animal could not possibly have walked on all-fours, as the enormously elongated ring-finger would clearly render this mode of progression an impossibility. It is clear, therefore, that in walking on the ground, the Pterodactyles must have been as genuine bipeds as birds; and the entire characters of the skeleton prove that this view is the correct one, and that the hind-limbs alone were used in supporting the weight of the body. To what use, then, did the animal put its wonderfully-constructed hands? In the reply to this question we have a very beautiful instance of the mode in which the naturalist is enabled to reason with certainty as to the unknown from what he already knows, and to re-construct the strange creatures of the past by observations made on the familiar animals of the present.

The only animals now in existence which possess a hand at all comparable to that of the Pterodactyles are the curious flying quadrupeds which we all know as bats, and in these the resemblance is accompanied by striking differences. If we look at the hand of

a bat (Fig. 4, C), we see that all the five fingers are present, the thumb being very small, and being furnished with a hooked claw; while the other four fingers are of immense length, and are clawless. The hand, therefore, is like that of the Pterodactyle (Fig. 4, A), except that, in the latter, three of the four fingers are short and clawed, and only one finger is lengthened out and clawless. We know, however, what function is discharged by the elongated and clawless fingers of the hand of the bat. We know that they serve for the support of a delicate expansion of the skin, or "wing," which stretches between the fore and hind legs, and is attached to the sides of the body, while a continuation of it is sometimes found between the hind-legs, inclosing the tail. We know that the long fingers of the hand are the principal agents by which this "flying-membrane" can be folded up or expanded for use, as the animal may desire; and we know that the membrane thus expanded and supported can be made by the muscles of the arms to beat the air in successive strokes, thus conferring upon the animal the power of genuine "flight." Judging, then, from what we know of the bats, we should be justified in inferring that the single greatly elongated and clawless finger of the Pterodactyles served for the support of a delicate "flying-membrane," or lateral expansion of the integument, springing from the sides of the

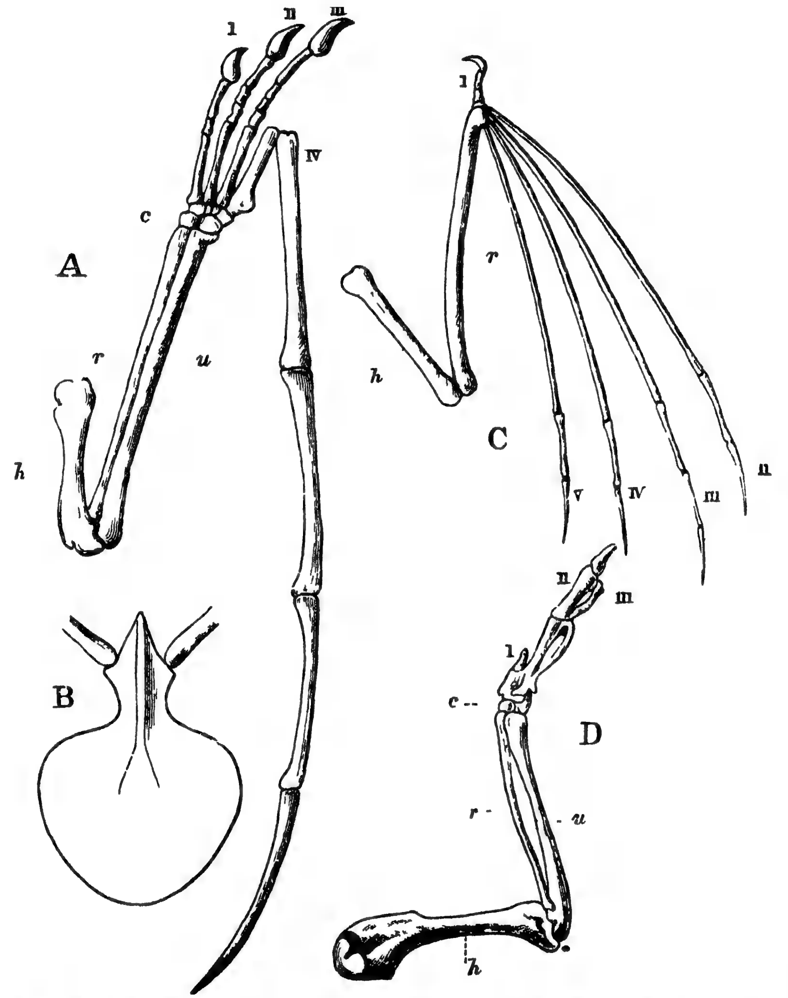



Fig 4—(A) Arm and Hand of a Pterodactyle (*Pterodactylus crassirostris*), (B) Breast-Bone of a Pterodactyle, showing the Ridge or Keel to which the Muscles of Flight were attached, (C) Arm and Hand of a Bat; (D) Arm and Hand (or "Wing") of a Bird, *h*, Bone of the Upper Arm, *r* and *u*, Bones of the Fore-Arm; *c*, Bones of the Wrist, I., Thumb; II, Fore-Finger, III, Middle Finger, IV, Ring-Finger, V, Little Finger

body, attached to the fore and hind legs, and extending from the hind-legs to the tail; and we should also be warranted in believing that this flying-membrane could be made by appropriate muscles to strike the air, in the same manner as the "wing" of the bats. In Fig. 5 we have given a representation, after Professor Owen, of one of the Pterodactyles, as it must have appeared in its living state; and from this the reader can at once judge of the form and proportions of the supposed flying-membrane of these animals. It follows further that, if this view as to the functions of the elongated finger of the hand of the Pterodactyles be a correct one, these animals must have been able to "fly," in as strict a sense as the birds and the bats; so that there is no real ground for comparison between the "flying-membrane" of the former and the lateral "parachutes" of such living reptiles as the "flying dragons;" the latter, as we have seen, having no power of true flight, but simply using the lateral folds of skin as supports in long leaps through the air.

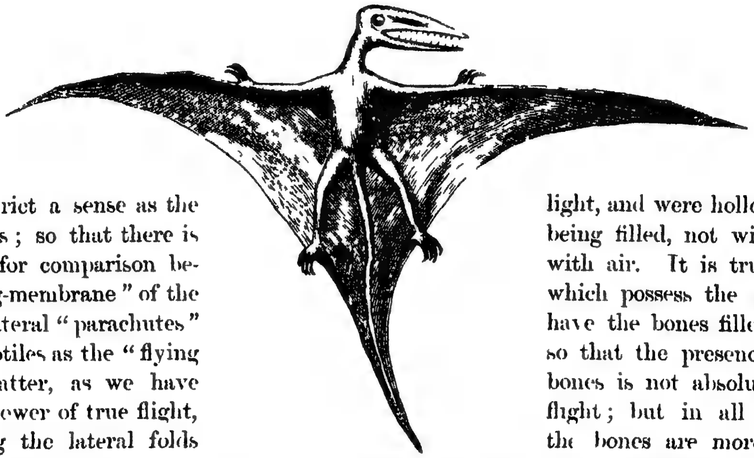


Fig. 5.—A Pterodactyle (*Dimorphodon macronyx*), as it would have appeared in its living Condition, greatly reduced in Size (*After Owen*). This form is remarkable for the unusual Length of the Tail.

It may be said, however, that this is all mere conjecture, and that we have no right to reason in this way, seeing that we have so far been unable to detect with certainty any actual traces of the "flying-membrane" accompanying the bones of the Pterodactyles. To this apparently plausible objection, it must be urged that the flying-membrane which the Pterodactyles are believed to have possessed, must have been so delicate that we could hardly expect reasonably that it should have been preserved along with the greatly less perishable bones; while we possess very important collateral evidence proving that these animals were able to support themselves in the air. Thus, we find that the breast bone of the Pterodactyles (Fig. 4, B) is furnished in front with a well-marked longitudinal ridge or keel of bone. A similar keel is found on the breast-bone of the flying birds, and also on that of the bats, and we know perfectly well what it means, and what is its function. We know, namely, that this keel upon the breast-bone is used for the attachment of the great muscles which move the wings; and the size of the keel is therefore a fair indication of the power of flight possessed by any bird, its size increasing in direct proportion to the strength of the muscles of the wings. We know that a few burrowing animals, such as the moles, in which the muscles of the arms are greatly developed, have a similar though less extensive keel upon the breast-bone; but as there is not the slightest ground for ascribing burrowing habits to the Pterodactyles, we are fully justified in believing that the keel upon the breast-bone indicates in their case the possession of powerful wing-muscles, and the consequent capacity for flight. Again, we know that the bones of the Pterodactyles were very light, and were hollow, their cavities being filled, not with marrow, but with air. It is true that the bats, which possess the power of flight, have the bones filled with marrow, so that the presence of air in the bones is not absolutely essential to flight; but in all the flying-birds the bones are more or less extensively hollowed out into air-cavities, and we can hardly be wrong in concluding that the existence of similar cavities in the bones of the Pterodactyles indicates a similar mode of life for the latter.

Upon the whole, then, we may safely conclude that the Pterodactyles enjoyed the power of genuine flight, and that the apparatus by which they supported themselves in the air was a flying-membrane, essentially similar to the "wing" of the bats, but differing in the fact that the chief agent in its expansion is a single elongated finger. It remains, accepting this as settled, to briefly consider the relationships which subsist between the Pterodactyles on the one hand, and the bats, the birds, and the reptiles on the other hand. From the bats, as we have seen, the Pterodactyles are distinguished by the different structure of the hand; but a distinction of more vital importance is to be found in the fact that the former possessed no air-cavities in the bones (this implying a very important difference in the structure of the breathing-organs), while the skull of the latter is built upon an entirely different plan to that which we find in the bats. We may,

therefore, decide without hesitation that the Pterodactyles cannot be placed in the neighbourhood of the bats, and, indeed, cannot be associated with the true quadrupeds ("mammals") at all. To the birds, the Pterodactyles exhibit many points of affinity, as seen more especially in the general structure of the skull and neck, and in the presence of air-cavities in the bones. These resemblances, however, cannot be allowed to count for much as against the striking differences which separate these two groups. If the Pterodactyles were really related to the birds, they must have been warm-blooded animals; in which case, as strongly insisted upon by Owen, they must have possessed a non-conducting covering of feathers. We have, however, no evidence that they were provided with feathers or with any integumentary appendages of any kind, and we have the reasonable right to interpret this negative evidence in a positive light, seeing that the rocks in which Pterodactyles are most abundant have actually yielded the well-preserved traces of feathers in connection with the bones of true birds. There is, therefore, every probability that the skin of the Pterodactyles was naked, a condition of things incompatible—except in animals capable of clothing themselves artificially—with the possession of hot blood. Moreover, the apparatus of flight in the Pterodactyles and the birds is respectively very different. In the former, the animal supported itself in the air by a "flying-membrane," carried principally by one elongated finger. In the latter, the fore-limb, or "wing," is only furnished with two fingers and a rudimentary thumb, and its entire structure is specially modified (Fig. 4, D) for the attachment of a series of quill-feathers, which constitute the actual apparatus of flight.

On the other hand, the balance of evidence at the present moment is very decidedly in favour of our considering the Pterodactyles as truly referable to the class of the Reptiles, and to be, therefore, essentially related to such existing animals as the lizards and the crocodiles. Not only do they agree with the Reptiles in very many important points connected with their skeleton, but the fact that they were destitute of either feathers or hair, and that they, therefore, were cold-blooded, will hardly permit us to associate them closely with any other known group of animals.

If this conclusion be accepted—and few now entertain views essentially different—we are presented in the Pterodactyles with one of the most remarkable of many extinct types of reptilian life. The power of flight, conditioned by the possession of a bat-like wing-membrane, supported upon one greatly elongated finger, and the possession of hollow bones filled with air, are points in which the Pterodactyles differ from all known reptiles; and they must, therefore, be regarded as constituting a group quite apart, within the limits of the class to which they belong. Nor can their general appearance when alive have been any more in accordance with our ordinary notions than their internal structure. They do not take the place of the true birds during the Secondary period, for we know that these existed as well; but they seem to have been the principal denizens of the air at this epoch of the history of the earth. The smaller ones may, perhaps, have lived upon insects; but the larger ones probably subsisted upon fish, their toothed jaws serving admirably to enable them to retain a firm hold of their slippery prey. The giants of the order—with skulls three feet in length, and wings twenty-five or thirty feet in expanse—appear, however, to have been destitute of teeth, though it is probable that they, too, lived principally upon fish. It hardly needs a great stretch of the imagination—now that we know something of the structure of these wonderful reptiles—to call up before our mind's eye a scene on one of the coasts of the Oolitic or the Chalk Sea, in which we may suppose the principal actors to be Pterodactyles. Each may fill up the details of such a scene as best pleases him. In any case, the predominant feature of the picture will be found in the presence of these weird and spectral creatures, some sitting on some projecting point of rock, watching with glittering eye the movements of the fish in the clear-blue water below; others beating with leathern pinions the dusky air, hovering above the unruffled surface of the ocean, and ever and anon darting down with rapid swoop upon their hapless prey; while others, possibly with many a dissonant shriek, wing their way steadily to some distant roosting-place among the cliffs.

# THE TIDES.

By William Durham, F.R.S. Edin.

MANY people, besides little Paul Dombey, in wandering by the sea-shore, and listening to the "eternal toil of ocean," have wondered "what the wild waves were saying." Their voice, however, is to most men vague and indefinite. But to one listener they speak in a manner which cannot be mistaken; lacking, it may be, somewhat in grandeur, but gaining vastly in precision, and leading at last to greater grandeur still, pointing the mind to considerations beyond the present, either in time or space. That listener is the patient and docile inquirer into the secrets of Nature, who finds in the contemplation of the marvellous beauty of her arrangements a rich reward for all his toil; who finds the poetry of knowledge no less elevating than the poetry of sentiment. Let us, then, in this spirit endeavour to understand a few of the things that the "great deep" is telling us.

Let us imagine ourselves living somewhere on the coast, and taking our daily walks on the beach. We can then note closely the various movements of the waters as they daily rise and fall, and thus make our visit not only interesting, but invigorating to mind and body alike. We cannot fail before long to observe the following facts, which we shall note in separate paragraphs for the sake of distinctness, as nothing helps us more in understanding the workings of Nature than distinctly noting down what we observe and wish to explain.

*Firstly:* The water gradually rises up on the beach to a certain height, then falls back again, or recedes to a certain distance, twice in about twenty-four hours. This flowing and ebbing motion is called a "tide;" and when the water reaches the highest point, it is said to be "high water."

*Secondly:* Observing the points of high water of the two tides on one day, we find that they are not always the same. That is to say, one tide *sometimes* rises higher up on the beach than the other.

*Thirdly:* Confining our attention to one of the daily tides, for convenience of observation, and observing it on different days, we find that it does not rise to the same height every day, but varies in a gradual manner, rising less and less every day for a few days, then rising higher and higher again for a few days more, till it reaches its highest point, when the same cycle of operations is repeated. It is exceedingly interesting to watch this motion of the tide. When it rises highest, it recedes farthest; and when it rises least, it recedes least; so that if the beach is tolerably level and uniform, and if we imagine a central line between high and low water, it vibrates about this central line like a vibrating-cord or pianoforte-wire, whose vibrations occupy about twelve hours each, and gradually become less and less in extent for some days, and as gradually become greater and greater again.

*Fourthly:* Again limiting our observations, as in the preceding paragraph, and noting, not the height to which the water rises, but the hour at which the highest point is reached on different days, we find that the hour is not the same every day, but is progressively a little later each day. In other words, there are more than twenty-four hours of interval between the high water of one day and the same high water next day. This interval is sometimes about twenty-four hours and a half, and daily extends till it reaches about twenty-five hours and a half, then gradually contracts again; and in about fifteen days the cycle is completed, and high water occurs at about the same hour.

Having thus made our observations, we must now look about for their explanation. In the first place, it will readily occur to us that the tides are of the nature of great waves following one another, with an interval of something over twelve hours between each, the crest of the wave being high water, and the hollow being low water. The fact that two of these waves pass in about one day suggests to us that the revolution of the earth upon its axis (which takes twenty-four hours to complete) may have something to do with the phenomena; but as it takes *more* than twenty-four hours for the two waves to pass, there must be some other influence at work besides the earth's rotation. In our fourth series of observations, we found that a cycle of tide-variations was completed in about fifteen days, or two of them in about thirty days, or a month. This time does not very much exceed the time which the moon takes to go round the earth, which is about twenty-eight days; and, as the earth and moon attract one another, may not the moon lift up, as it were, the water of the ocean into the shape of a wave as it passes round its course? This consideration introduces a new feature of interest for our observation, and on comparing the tides

with the phases of the moon we notice some remarkable coincidences. We find, for instance, that the highest tides always occur about the time of new and full moon, and the lowest tide about the first and third quarters.

Hitherto we have been treading on the sure ground of facts, which any person may verify by the simple use of his eyes. Now, however, we must advance a little into the more dubious region of theory, and use our reason a little. For the full understanding of the theory of the tides, attainments of a high order are requisite;* but the general principles can be understood and appreciated by any person of ordinary common sense.

Let us suppose that the earth is a regular globe, with a covering of water of uniform depth all round it (like Fig. 1); E being the earth, W the water round it, and M the moon above.

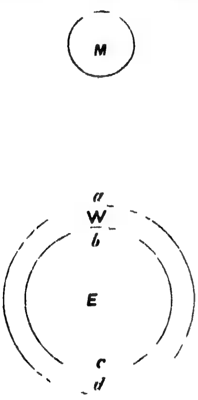


Fig. 1.—Diagram illustrating the Relations of the Moon, the Earth, and the Sea.

Then, as the attraction of gravitation is greater the nearer the bodies are to one another, it follows that the moon will attract the water at $a$ with greater energy than it will the earth at $b$; therefore the water will be lifted up, as it were, like what many of us may have seen happen when a body charged with electricity is passed near a person's head -the hair rises up towards the electrified body. Again, the attraction of the moon for the earth at $c$ is greater than for the water at $d$, and the result is the earth will be dragged away from the water. From these effects of gravitation, and from the fact of water being a fluid, the water will no longer remain uniform round the globe, but will assume something like the form represented in Fig. 2, being higher at $b$ and $c$, and lower at $f$ and $g$.

Having thus got a sort of permanent high and low water arrangement, we may next examine the effects of the earth's rotation in twenty-four hours on the relative positions of high and low water. It is quite evident that, as the earth revolves in the direction of the arrow, the point $b$ will be brought successively into the places of the points $f$, $c$, $g$, before returning to its original place, and in so doing will pass gradually from high to low water, and from low to high twice in twenty-four hours; and that there will be an interval of twelve hours between one high water and another, supposing the water arrangement remains stationary.

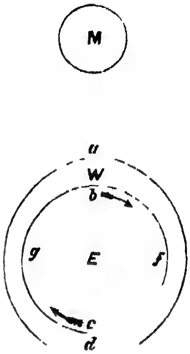


Fig. 2.—Illustrating the Attraction of the Moon on the Waters of the Earth.

We now seem approaching an explanation of the tides; but we still have some work before us, because our observations do not altogether agree with what would be if our explanation were complete. For instance, we observe that the interval between the high water of one day and that of the next was not 24 hours, as it should be by the explanation, but was sometimes as much as $25\frac{1}{2}$ hours. How are we to account for this? In our explanation we supposed the water arrangement in Fig. 2 to remain stationary; but a very little consideration will show us that this is not exactly correct. It depends, as we have seen, on the influence of the moon, and of course if the moon change its place, so also will the water arrangement. As we all know, the moon goes round the earth in about 28 days, and therefore every day it will go a 28th part round the earth. In consequence of this, when point $b$ has gone quite round with the earth in 24 hours, and arrived at its starting-point again, the moon will not be right above it as before, but somewhat to the right hand, and will have carried with it the point ($a$) of high water; so before $b$ reaches high water again, it must travel from $b$ to $b_2$, and this of course will occupy a little more time. Fig. 3 will make this clear. The dotted circle marks the moon's original place, and M the new place at the end of 24 hours.

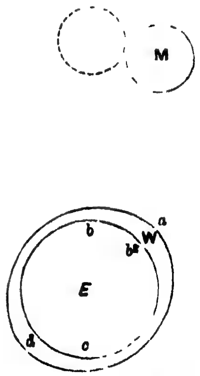


Fig. 3.—Diagram to explain how the Interval of Time between the High Water of one Day and that of the next is not 24 Hours.

This explains very well how high tide should take more than 24 hours to come round again; but it does not explain why that time should vary: why, for instance, it should take $24\frac{1}{2}$ hours at one time, and $25\frac{1}{2}$ at another. Neither does it explain

* In which connection we may refer the reader to the "Manual of the Tides, and Tidal Currents" (Galbraith and Haughton's Scientific Manuals)

why the point of high water should be lower or higher at one time than another, which we know from our observations to be the case. Before extending our considerations further, let us turn for a little to our second note, “*That the points of high water of the two daily tides are not always the same.*”

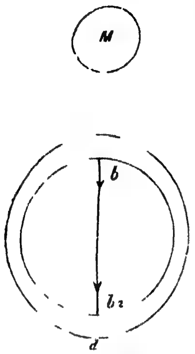


Fig 4. — Diagram to show how the Points of High Water of the two Daily Tides are not always the same.

Let us suppose Fig. 4 to represent, as before, the moon, water, and earth, but revolving in the direction of the arrows, from the top to the bottom of the page, instead of from left to right, as in former figures, then any point $b$ in 12 hours would come into the place of $b_2$, and as the water is symmetrical round the globe, the height of tide will be the same in both positions; but this would only happen when the moon was directly over the equator or central line marked by the arrows; but it is not always so, but is sometimes on one side and sometimes on the other. Let us suppose it is as in Fig. 5. It is easy to see that, the earth revolving from top to bottom of the page, as we have mentioned, at the point $b$, when, after 12 hours' rotation of the earth, it reaches the point $b_2$, the tide will not be quite so high.

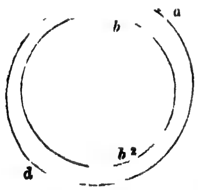


Fig 5.—Diagram to show how in the Revolution of the Earth the Tide is sometimes not so high at one Time as at another. The Position of the Moon in the Figure is purposely exaggerated, to bring out more clearly what is meant.

Hitherto we have considered only the action of two bodies in reference to the tides; but there is the sun to be taken into account, and from his great size we would almost imagine that his influence would be more powerful than that of the moon; but it is not so, and the reason is clear enough. Although his size is so great, he is nearly 400 times farther away from the earth than the moon is, and in consequence of this the moon has, roughly speaking, more than twice his power of arranging the water in the tidal form we have shown in our figures. The sun's influence, however, though thus much less than the moon's, cannot be left out of sight if we are to get a proper explanation of the tides. We have to unite the tides which the sun and the moon would separately produce, and see if the result throws any further light on our observations. All we have said regarding the production of tides by the moon's influence would equally apply to the tides produced by the sun, modified, however, by the fact that the sun takes about 365 days to complete his *apparent* revolution round the earth, instead of 28 days, as the moon does. We shall now proceed to examine the joint action of the sun and moon.

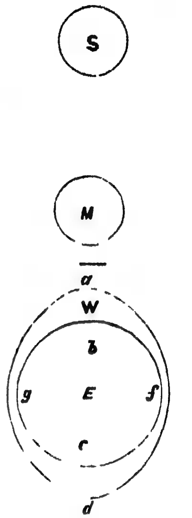
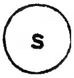


Fig 6. — Diagram to illustrate the Joint Action of the Sun and Moon in producing Tides — especially Spring Tides.

Let us suppose (Fig. 6) that the sun, moon, and earth are in the same straight line: S being the sun, M the moon, and E the earth; $a$, $b$, $c$, $d$, $f$, and $g$ denoting the same points as before. In this case, we shall have the tides due to the sun and moon superposed, and we shall have very high water at $b$ and $c$, and very low water at $f$ and $g$. As we have seen, the moon moves more quickly in its course round the earth than the sun, consequently will rapidly leave the straight line joining the earth and the sun, and in doing so will carry with it its share of the high tide, and when it completes its first quarter, the two tides due to the sun and the moon will be at right angles to one another, and instead of being superposed, they will partially neutralise each other.

The result is some such arrangement of the water as in Fig. 7, which approaches the form of a circle much more than Fig. 6. As the moon, however, has twice the tide-producing power of the sun, the crest of the tidal wave will still be nearly under it, as at $a$, so that there will be high water on the earth at $f$ and $g$, and low water at $b$ and $c$; but the high water will not be nearly so high, nor the low water so low, as in Fig. 6, when the sun and moon are in a straight line with the earth. In fact, Fig. 6 represents what is usually called “spring tide,” and Fig. 7 “neap tide;” the former being the highest and the latter the lowest semi-monthly tide. These phenomena will be repeated in an inverse order as the moon moves on in its course. When the moon arrives at the opposite

side of the earth from the sun, but on the same straight line, or at "full moon," there will be "spring tide" again at *b* and *c*, and when the moon reaches its third quarter, there will be "neap tide" at *f* and *g*. Thus there are two spring tides and two neap tides every revolution of the moon round the earth. This agrees with our observations, and gives us a reason for the varying heights to which high water rises—viz., the varying positions of the sun and moon relative to the earth.




We have now to explain the reason why the interval between the high tide of one day and the high tide of the next should vary, why it should sometimes be $24\frac{1}{2}$ hours, and sometimes more, till it reaches $25\frac{1}{2}$ hours. If we turn to Figs. 6 and 7, and consider the action of the sun and moon on the water, we see as the moon moves away from its position in Fig. 6 towards that on Fig. 7 it drags the crest of the tidal wave away with it; but the sun also tends to keep the crest of the wave back towards the point *b*. The result of these antagonistic actions is that the tidal wave is kept back or retarded behind the moon somewhat, till it passes its first quarter. After it passes that position, the action of the sun tends to carry the crest of the wave towards the point *c*, and this tends to hurry on or accelerate the progress of the tidal wave, more than the moon's action alone would do, until it is full moon. This process is repeated as the moon passes to its third quarter, and then to new moon. This gradual retardation and acceleration gives a pendulum-like swing to the tides. If we imagine the crest of the wave to be the bob of the pendulum, it rushes from its slowest point with gradually increasing velocity till it reaches its fastest, then gradually gets slower again, and makes, as it were, two swings in the time the moon takes to go round the earth. This motion quite explains the variations in time of the tides; for when the wave is travelling slowest the point *b* in Fig. 3 comes more quickly up to the crest of the wave than it does when the wave is travelling at its fastest rate.

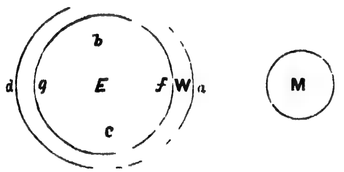


Fig 7.—Illustrating the Theory of Neap Tides.

We have thus pointed out in a general way an explanation of the various phenomena we noticed in the ebb and flow of the tides, and conclude that they are due mainly to the joint action of the sun, moon, and earth, as they change their relative positions in their various rotations. Of course, we have imagined the earth to be perfectly globular, and the water uniformly distributed round it, and as neither of these conditions obtain in the actual earth and ocean, we shall find many things modifying our conclusions; but in the main we shall find them accurate. It is not the purpose of this paper to go minutely into details, but one or two points may be mentioned as influencing the actual tide at different places.

Neither the sun nor the moon is always at the same distance from the earth; they both, within certain limits, regularly approach to and recede from the earth. This action of course affects the tides, making them higher or lower than usual. Should the sun and moon both be at their nearest point to the earth at once, and also be in the same straight line, then a very high tide indeed will be the result, as will be evident from what we have said as to their action. It is to be remembered also that the sun changes its apparent position, as well as the moon, and consequently causes another slight and gradual variation in the position of the tidal wave. The height to which the tidal wave rises in any given place is greatly modified by the form of the land round about, for it is easily understood that if the great ocean tidal wave in its course meets a narrow opening landwards, which quickly spreads out into a larger space, the part of the wave which enters the narrow has to spread out, and of course will get lower and lower as it spreads. Conversely, if the tidal wave enters a wide opening which gradually narrows, it will, as it rushes up, gradually contract in extent, and in the same measure increase in height. From these causes we have tides of various heights in various places; in one place rising only a foot or so, and in others sometimes as much as 120 feet.

It will be evident from what we have written that the full interpretation of the phenomena of the tides is a problem of no little difficulty, although in general outline it is simple enough. Still, it is exceedingly interesting to watch the general agreement of the facts with the theory; to notice, for instance, the gradual rise and fall of the point reached by high water as the moon gradually increases in age, from new moon to new moon; or the general agreement of the time of high water with the hour in which the moon passes the meridian or middle point of its course across the visible portions of the heavens; or the varying retardations and

accelerations of the tides as the sun and moon change their relative places.

There is one more fact connected with the tide which has attracted considerable attention of late years, and which is worthy of our consideration for its far-reaching consequences. As we have endeavoured to show, the tides are caused mainly by the moon, as it were, catching hold of the water as the earth revolves round on its axis. This must cause friction on the earth as it revolves, and friction, as every one knows, causes loss of power. Suppose a wheel with hair round its rim, like a circular brush such as is used for hair-brushing by machinery; if this brush be revolving rapidly, and we hold our hand ever so lightly on the hair, so that it is slightly rubbed backwards as the wheel revolves, we can understand that the speed of the wheel will be gradually diminished, until at last it will be brought to a standstill, provided there is no additional power communicated to the wheel by machinery or hand beyond what was given to set it spinning round. Now this is somewhat analogous to what is happening to the earth in its rotation. There is reason to suppose that the action of the tides is slowly but surely lessening the speed of the earth's rotation, and consequently increasing the length of the day, and that this action will continue until the earth revolves on its own axis in the same time that the moon takes to revolve round the earth. Then the day, instead of being twenty-four hours as now, will be about twenty-eight days, and the earth will be exposed to the full blaze of the sun for about fourteen days at a time. The change this will bring about on the face of the earth can hardly be exaggerated. All life, both animal and vegetable, will be destroyed; all water will be evaporated; the solid rocks will be scorched and cracked, and the whole world reduced to a dreary and barren wilderness. It is supposed by some that the moon has already passed through all this, which explains its shattered and bare-looking surface. The earth being so much larger has more quickly acted upon the oceans which once were upon the moon's surface, and stopped almost entirely its revolution round its own axis, thus causing it to have a day equal to twenty-eight of our days, and the heat of the sun has already done to it what in future ages it will do to the earth.

Thus, as we listen to what "the wild waves are saying," we hear them telling many things. They tell of the ceaseless march of the ground under our feet as it revolves round the central axis. They tell of the grander movements of the great orbs of heaven, and faithfully chronicle their every change. They startle us by a warning that the earth is growing old, and his steps beginning to fail; that his movements are slower than they were in bygone times, and that the time must come when the sterile barrenness of old age and death will come upon him also, as well as on all created things. Thus by the contemplation of the waves that ripple at our feet we are led on to study the majestic movements of the heavenly bodies, and to look from the present time to that far-distant future when this fair world of ours will be reduced to a burning, lifeless desert. Truly we wonder not that the human mind listens in awe to the ceaseless music of the mighty deep, and for ever asks,

"Is it a friendly greeting,
Or a warning that calls away?"

## RIVERS: THEIR WORK, AND CAÑON-MAKING.

BY PROFESSOR P. MARTIN DUNCAN, F.R.S., F.G.S.

EVERYBODY likes to look at a flowing river, and to watch the eddies and currents as they whirl floating things along, or wave the long weed on the bottom; but few people reflect upon the cause of the river, and what it does, or know the complicated work Nature has to perform before a drop of water runs down to the sea. As weeks of hot weather elapse, and the country becomes dried up, the river still flows onward; and if it is a large one, nearly the same quantity of water passes along day by day. When the rain has fallen heavily for some time, how different is the scene! The river is full, or has overflowed its banks, and the water extends for miles; it is in tumultuous and rapid movement, and often trees are carried along, houses are destroyed, bridges are broken, the power of the flood being fearful. The rain ceases, the flood falls, and the ordinary amount of quietly-running water flows along as usual; but there has been plenty of mischief done,

and if it be examined into carefully, some notions may be got about the way in which the valley was made in which the river flows. Two things may always be noticed to have been done:—*Firstly*, some stones, or gravel, or bits of rock, which formerly formed the sides of the river, have been removed, and may be found much lower down the stream, towards the sea. *Secondly*, the river has deepened its bed—that is to say, some of the bottom or floor is scooped away, and the stones have been swept seawards. In civilised countries where much care is taken to protect the river-sides, these occurrences are not so well seen; but in other places there are extraordinary instances of the effects of river-floods to be observed. In some of the rivers of Bengal the scour is tremendous; and in one, stone and earth to the depth of 90 feet is removed every year from the river floor, and the channel is deepened by so much. All the accumulation there during the rainless months, when stone is carried gently along and collects in the holes and deeps, is washed out and carried to the sea. It is evident, then, that during flood-time solid substances forming part of the neighbourhood of a river, and a portion of its bed, are removed, and that the river fashions its channel out of the land. In the long run, the river removes the land to the sea, and enlarges its channel, until a time comes when its power of doing all this diminishes—that is to say, when the water in the flood-time is not in great quantity, and its movement is not very rapid. This occurs when rivers grow old; for they are lively and full of mischief in their early days, when they scoop out their valleys and send the worn-off stone and mud to the seas; but in time the work is done, and the river, formerly wild, becomes tame, and does not even move enough stone and mud to the sea to keep its path straight.

Anybody who thinks over this matter, will soon see that the power of a river depends on the quantity of its water and the pace at which it is moved along. Common sense leads to the belief, that the more rain that falls, and can get into the river, and the greater the slope of the river-bed towards the sea, the greater will be the effects of the moving water. If there is an unusually small quantity of rain, the floods will be less; and if, during ages, the river cuts its channel down nearer to sea-level than before, for miles and miles inland, there will be all the less slope and consequent movement in the water. It is a question of water-supply and readiness of running off, that has to do with the story of the formation of a great river-valley. What is meant by a river-valley? A large river-valley opens at one end, either into the sea or into lakes; it is bounded at the sides by land higher than the river, and sea, or lake, and at the farther end and near the source the land is higher still. The streams flow down a slope of greater or less length, breadth, and pitch, and this sloping land, encircled on all sides but one—where the sea or lake may be—by hills, is called in the language of science a "catchment" or "hydrographical basin." The summits or tops of the hills are called the water-partings, and their sides and tops towards the river form the watershed. These terms mean, that rain falling on the hills will run down them either towards one slope or another—they part the waters of valleys with rivers in them, and which may be situated on either side. The sides of the hills down which water can run into a particular river, are the watersheds of that river; and the great space between the distant hills is the catchment or rain and water-catching basin. The term "hydrographical" refers to the possibility of calculating the amount of rain that falls on the space limited or bounded by the hill-tops, and traversed by the river and its streams, and of estimating the effects of it on the land.

A catchment-basin should include all the branches of the main river, and the land around them, up to the top of the hills which act as water-parters. These basins are of different sizes, according to the distance of the high land, whence the river springs, from the sea into which it flows, and also according to the number of the branches and their lengths. The basin of the great river Mississippi, including the branches, occupies a large portion of North America; but that of the Thames, limited as it is on all sides but one by low hills, is very much smaller, but is quite as perfect. In the instance of the "great river-system," as it is called, of the Mississippi, there are important branches which run into the main river. These may be said to have their catchment-basins, and the main river is a sort of sea to them; but really, all the side valleys that come at last down to the great plains through which the parent river wanders, belong to the same system of carrying off or drainage. These rivers drain the land of their catchment-basins; and there is some relation between the quantity of rain that falls on their surface in a year, and that which runs off by the streams in the same time.

A short journey will explain much about rivers and their valleys to any one who can think a little. Going by rail to the West of England, the valley of the Thames is traversed, from London, by Windsor, Reading, and Oxford; and then an excursion will lead, up the river, by Lechlade, Cricklade, to Cirencester. Some miles south of this last-mentioned town, there is Thames Head, the springs of which we may assume to be the source of the Thames. During this journey the hills to the north and south of the flat plain, through which the river runs, are visible enough, and at last they come closer together. They are the "watersheds." A gradual rise of the ground has occurred, for Oxford is higher above sea-level than London, and Thames Head than Oxford. Standing close to where (before the Thames and Severn Canal dried up the most distant springs) the important river rose in Trewsbury Mead, the height above sea-level will be found to be about 330 feet.* But the summits of the hills there, from which water can get down towards the Thames, are about 500 feet above sea-level. These uplands get higher towards the north, and attain 718 and 1,084 feet, and thus some of the northern branches of the Thames have a higher watershed than the river into which they pour. The whole of these branches of the Thames are within its catchment-basin; and just on the other side of the hills are the catchment-basins of other rivers, such as the Severn, the Avon of Wilts, the Avon of Warwickshire, the Nen of Northampton, and the Ouse of Bedfordshire. On walking up the hills going west from the origin of the Thames, at last the valley of the Severn is seen, hundreds of feet below; so that, within a few miles, several streams are rising at a height of more than 300 feet on the east, whilst, on the west, there is the great plain with Gloucester on its river. The hills are the Cotswolds, and they are the water-partings of the Thames and its western branches, and of the Severn. The length of the main valley of the Thames is computed at 120 miles to the Nore; and as the most distant river-point is only 330 feet above sea-level, the slope of the valley is very slight. The river winds about, and has the length of 210 miles. If we consider that the highest hills of the Cotswolds, such as Cleeve and Edge Hill, form part of the watershed, then the extreme height is 1,084 feet, down which water pours. The tide comes up the Thames, but not so far as formerly, for it is stopped by a weir and lock at Teddington. Hence, in all calculations, the Thames may be said to end at Kingston. Above Kingston the catchment-basin, when measured, has a space, or "area" as it is called, of 3,675 square miles; and of course some of the rain that falls on that surface gets to the river, and carries down soluble matter and the wreck of the land. In uncultivated countries, where the land around the sources of a river is mountainous, the stream may rise some thousands of feet above the level of the sea, and then its course is divided into parts, according to the nature of the river's bed or bottom. In mountainous districts, rivers arise in torrents and wild roaring streams, which tumble the water over rocks and amidst boulders, at a great pitch. These are the torrent portions. Then, as the edge of the high land is passed, and the river enters the open country, a fall often takes place, and cataracts or waterfalls are seen. This part of a river is called the cataract portion. Then comes the less quickly-flowing part of the river, where it curves here and there, running often sluggishly; and this is in the midst of plains or valley-bottom land, which is liable to be flooded by any unusual outpour of water. These portions of the river's valley are called flood-plains. Finally, the river enters the sea by one or more channels, and sometimes through a delta.

Some rivers arise from streams of water that flow out from beneath glaciers on high mountains, and a few appear to commence in mountain lakes; but even in these instances, the idea of the catchment-basin holds good. One thing is very certain, although it is opposed to a curious popular error, and it is, that a very small quantity of water issues forth from the earth at the origin or source of the river. It has been thought that the springs of the commencing river contribute principally to its amount of water, but this is an error. Thus the quantity of water that flows from the Thames head and thereabouts is 500 cubic feet in a minute, and this is a very minute quantity in relation to the 1,380,000,000 of gallons that pass daily by Kingston. Many tributaries, of course, go to swell the amount, but their source-springs do not contribute over-much; and indeed, in one remarkable instance, the branch of the river sends less water into the main stream than it gets from the source-springs. This was shown to be the case of the river Churn, which rises to the west of Cirencester, and at a height of 680 or 700 feet above the sea. There are several sources, and one well

* These details are taken from Phillips's "Geology of Oxford and the Thames Valley," a most charming book.

known and visited is that of the Seven Wells. There, beautiful, clear, pure water bursts up briskly through natural cracks in the solid rock, and forms a small rivulet. In the dry autumn of 1859, the late Mr. Simpson, the engineer, made some estimates about the amount of water supplied by the springs to the Churn, and by this to the Thames. He found that 11 cubic feet of water was discharged from the spring-head in a minute, and that a quarter of a mile down the stream 31 cubic feet was passing along in a minute, and that at a mile 73 cubic feet went along at the same time. Hence water got into the stream from some other source than the spring-head. At five miles and a half no less than 320 cubic feet passed over the bed of the river in a minute, so that there was a very considerable increase. But farther on, the river, instead of increasing in its amount of water, began to get smaller, and where it was fourteen and a half miles from its source, it poured only 10 cubic feet along in a minute. The water increased in the river up to a certain amount, and then gradually fell off to less than that poured in first of all. This was accounted for upon a principle which requires attention. The first part of the river poured along a bed of clay, down through which water cannot pass; but the second part passed over a hard rock called *oolite*, which is full of cracks and crevices, and into them went the water instead of passing along. The first kind of bed, that of clay, is said to be *impervious*—water cannot soak into it and be lost; and the second, the oolite, is *porous*, and full of cracks. Hence clay and suchlike layers of earth, or strata, are called *impermeable*, and limestone, chalk, gravel, and sand in layers are called *permeable* strata. These terms must be remembered, for the arrangement of the divers kinds of layers of earth in a valley has to do with many important things connected with rivers.

But how was it that the water increased as it flowed over the impermeable clay? The answer is that rain-water, sinking down into the soil, passes down a pervious subsoil, and comes in contact with the dense clay, and runs on its surface, subterraneously, until it flows out into the stream, which has cut its bed lower than the top of the clay. There is then a supply of small springs on the top of the clay, for the water collects there during wet weather, and discharges so many cubic feet in a day during dry weather until all is exhausted. Lower down the stream, the rain-water passed into the porous strata, and got lower than the bed of the river, and did not add to it in any way. In some countries the upper layers of the earth are so very permeable by water, that rivers of any size

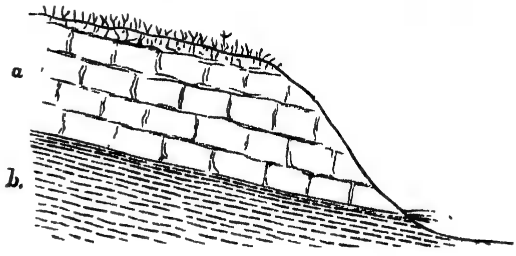



Fig. 1.—The Source of a Spring.
*a*, Permeable strata; *b*, impermeable strata.

and length cannot exist. The constant and average amount of water in a river is due to springs at its head and along its course, wherever impermeable strata are capped by permeable.

If a river were to run in the midst of dense stony land, without cracks or crevices in the solid earth, it would be a torrent in wet weather, and a dry watercourse in the dry season; on the other hand, if the stream passes along a very permeable soil, with equally permeable rock beneath, it will not carry all its water to the sea; and, indeed, some streams disappear altogether under the circumstances. Floods are produced by water running off the impermeable strata in excess; and springs give the average supply of water in quiet weather.

Understanding, then, the relation of springs to the perpetual flow of a river, and of excess of rain to its floods, it is necessary to consider the amount of rain that gets to a river, and how far the streams may be said to drain and wear the catchment-basin. The quantity of rain that falls day by day can be calculated by measuring the amount which collects in a rain-gauge, and thus so many inches are said to have poured down in a year. These gauges are placed in several parts of the catchment-basin; and it is found that different amounts of rain fall in different parts of the country surrounded by the water-parting hills. A calculation is made, after several years' observations have been completed, regarding the average fall over the whole space during each year, and then it is stated that a certain number of inches of rain fall on the catchment basin during a twelvemonth. This amount varies in different valleys and in different counties of England, and it is hardly the same in any part of the world. Nevertheless, the quantity of rain that falls within the carrying-off power of a river can be estimated year by year. About 3 feet of rain (36 inches)

falls on the high lands around the head of the valley of the Thames; at Oxford the fall is, on an average, not more than 2 feet in the year; and it is less, probably, nearer the sea. Suppose that on all the space inclosed by the watershed of the Thames above Kingston (3,675 square miles) 28 inches of rain fell in the year—for that would be about the mean quantity—how much of this would come off by the river in the same time? The quantity of water that comes down in dry, in wet weather, and in flood-time during the year, has been calculated, but it does not amount to more than one third part of the rain that falls in the twelvemonth. What becomes of the other two-thirds? This question can be answered, and the explanation of the small quantity really carried away by the river can be given, by observing the effects of rain in different parts of the valley through which the river runs. After a smart shower on a clay soil—an impermeable stratum—much water runs off into ditches and brooks, and goes down to the stream and then to the river; but a good deal is left, having wetted the soil and formed little pools and puddles. All this is dried up, and does not go to the river; it is said to be evaporated, and it passes up into the air in the form of invisible vapour. Some of the rain does sink in, for clay is found to be always wet a few feet down. Plants take up a good deal of the rain, and build it up into their structures; but most of this moisture thus received is evaporated from the leaves. A different state of things happens on a chalk, limestone, or gravel soil, these being permeable strata. The rain sinks in and passes down through the earth to a certain and variable depth; but little runs off into streams to get to the river, much is evaporated, and some goes to vegetation, and a portion comes forth as spring water into the river. As there are more of these strata in the valley of the Thames than of the dense impervious kinds, more rain sinks into the earth than runs off suddenly by the river. A great proportion, indeed, of the rain never comes near the river at all, but sinks down far beneath it for hundreds of feet into the earth.

There is a remarkable thing to be noticed about the river Thames and the river Severn. If it rains much for a few days, the Thames will get very full of water, but will not overflow its banks; but the Severn and its branches to the north and west soon overflow and produce floods. Why is this? In the catchment-basin of the Thames above Kingston there are more permeable strata near the surface of the earth than impermeable ones. Consequently, a vast quantity of rain-water sinks into the earth, thence into the permeable strata, and either passes far below the river or is laid up in store for springs. There are about 2,424 square miles of such strata out of the 3,675 square miles of the whole catchment-basin. The catchment-basin of the Severn has a preponderance of hard strata which will not let the water in, so it has to run over them, and the result is flood.

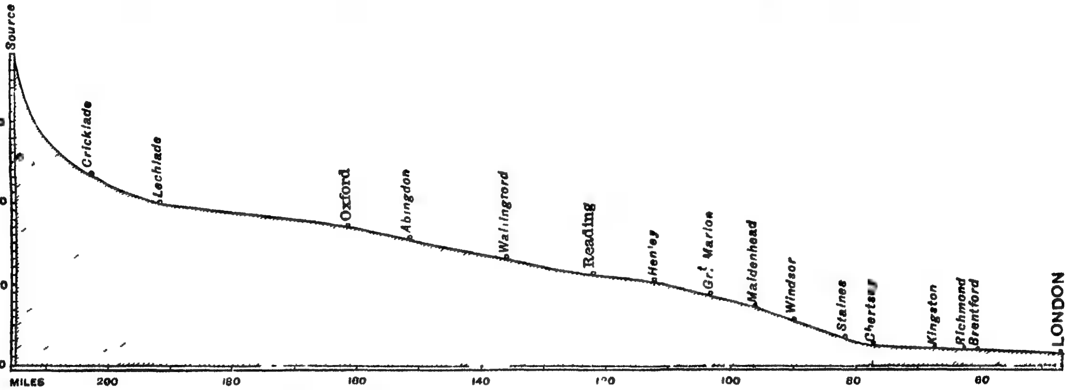



Fig. 2.—Course of the Thames from its Source to London.

This is interesting, and it shows the influence of the events of the geological ages when the strata were made, upon our present rivers and water-supply. The rain-water that goes down the permeable soils and strata, soaks them to a great depth; for on making cuttings or tunnels through such earth as chalk, for instance, it is always found wet. The water is stored up in the strata, and it may be disposed of by nature in several ways. Some is evaporated from the dry crust of the surface-soil, and some flows deeper and deeper until it collects at last on the top of a stratum down through which it

cannot get. This happens when a deep, dense stratum or a layer of clay underlies the porous one containing the water. If there is the least tilt of the impermeable and lower stratum, the water will move in its direction. This statement holds good, whether the thickness of the upper porous layers is a few feet or a mile. In the instance of the lower impervious layer being very deep, of course, none of the water can get into the river, but when the layer is shallow, or as seen on a hill-side, there is a chance of the water pouring out gradually as a spring, which will flow into a river.

friction of the water rushing along, assisted by the stones it rolls; and the underground waters carry off soluble rock to the river and leave spaces which form subterraneous caverns, and lead to the formation of underground rivers.

Thus the rain carries off the surface of the valley inch by inch, and widens, deepens, and lengthens it.

Time, a constant flow of water sufficiently swift to move stones rapidly on the bed of the river, and occasional floods—which bear great masses of rock, boulders, and gravel along, wearing everything in their way—were necessary to the formation of many of the deep valleys which are situated in the torrent and cascade portions of some rivers. Rain and the ordinary wear of the surface are not important agents. Such gorges as that which leads from the Falls of Niagara to Lake Ontario, in Canada, have been worn by the action of running water and moving stone, which have cut down the solid rock for miles in length, nearly 400 yards in breadth, and from 200 to 300 feet in height. The sides of the gorge are steep, and the wearing water comes down the river, and not from springs at the sides. The falls, where a vast volume of water pours over rock, are gradually wearing their foundations away, and some day or other they will have cut down the rocky bed over which they pour, and will thus increase the length of the gorge. Probably the

Fig 3.—Falls of Niagara.

Thus, the rain-water that falls on the chalk hills to the south of London, sinks in and goes down for hundreds of feet, to be stored up and tapped by very deep wells. None of it goes to the river. But the rain that falls on Highgate, Hampstead, and Harrow, goes through a few feet of gravel and sand only, and then comes to a clay which stops it. Consequently, on several sides of those hills there are springs just where the clay and gravel join and crop out, as the saying is, on the side of the hill.

Probably, about one third part of the rain that falls on the catchment-basin runs off by the river during the year, and one-sixth of this is derived from springs.

The catchment-basin is worn by water-action above and below ground. The streams, torrents, and large rivers wear their beds and banks by the

falls have receded from the lake into which their resulting streams run, seven miles off, and the slit-like valley has thus been excavated. In this instance the constant supply of water comes from Lake Erie, higher up the country than the falls (Fig. 3).

The wearing down of the most extraordinary gorges in the world, and the cutting of their vast chasms out of solid rock, have been produced by similar causes, but the action of rain on the surrounding country is very slight, the country being comparatively, now, rainless. The cañons of the western territories of the United States—in some instances a mile in depth, in deep shade at the bottom, and at one time traversed by a comparatively quiet stream, and at others by a downward rush of tumultuous waters, carrying large masses of stone along—are often scores of miles in length, and resemble cracks in the earth rather than water-courses. The country in many places is so intersected by these cañons that the drainage of the surface on which very little rain falls, is so rapid that great sterility results; but the water that may come into these long channels at the sides is of little importance. They drain important mountain regions far off, and snow and glacier ice supply a quantity of water which, passing down along a very considerable slope, receives a great velocity and wearing-power. The wearing of the sides, from the ordinary agents of denudation, and the very small quantity of rain, is inconsiderable in relation to the depth. But things were different when they were first formed and cut down; there was then a greater water-supply, and in some instances movements in the earth assisted the cutting down of the rocks and the removal of the resulting gravel and stone (Figs. 4, 5).

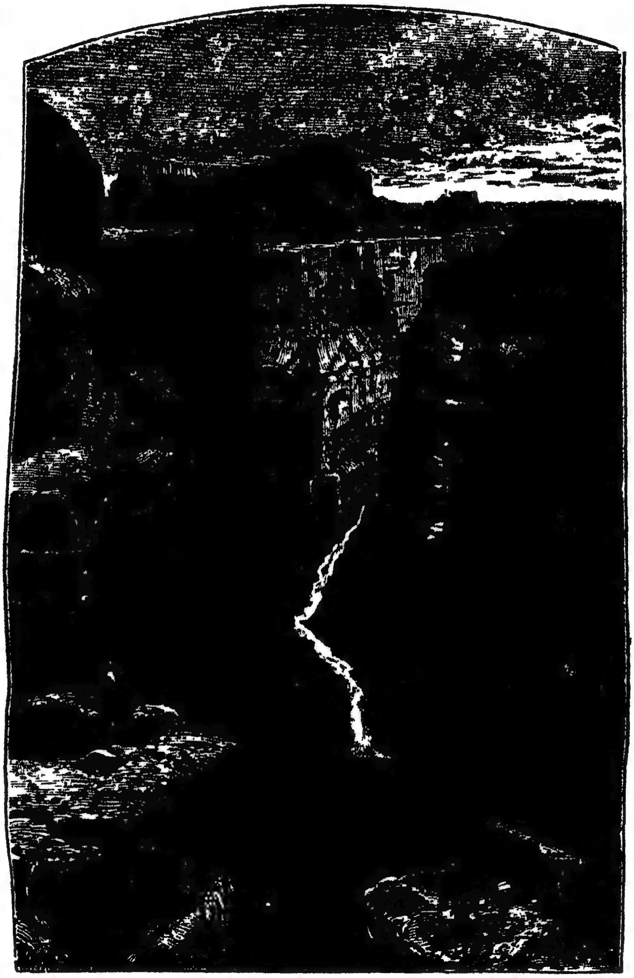


Fig. 4 – The Cataract Cañon.

It was formerly a country of great lakes, which were not much above the level of the sea. The land was upheaved gradually, and the lakes—then many hundreds of feet above their former level—began to pour through natural creeks, and along the line of old streams to the sea. The drainage of the catchment-basins in which the lakes were, was vast, and it flowed into these vast receptacles of water, so that a great supply of water-power was ready to act on the rapid slope to the sea, and the evaporation from the latter supplied snow to the mountains, and this fed the lakes again. Cataracts were formed, and their floor was worn backwards, and the power of the water to produce friction was maintained by the gradual uprise of parts of the district maintaining the pitch. The lakes became dry as the cañons were perfected, and these deep V-shaped chasms remain as evidence of a long lapse of time, and of the work of the constant rush of water and stones on solid granite and on limestone and sandstone rocks, without the concurrent action of rain and the ordinary denuding agents of valleys (Fig. 6).

The cañons of the Colorado are magnificent beyond description, and the river-system drains an area of vast extent. That is to say, the

catchment-basin is about the third in its extent in North America, those of the Mississippi and Columbia being the largest. The Grand Cañon is much longer than the valley of the Thames, for it exists as a gorge for over 200 miles, and its depth is not less than 4,000 feet. Two rivers — the Grand and Green Rivers— unite in the eastern part of Utah, and a vast waterflow occurs. The amount of water is great, the pitch of the bed is rapid, and thus a great power is at hand, possibly equal to that of the flow of the Falls of Niagara. The rivers meet in a narrow gorge, more than 2,000 feet deep, and then the cañons begin. The first is called Cataract Cañon, and the descent of the river is rapid (Fig. 4). The velocity of the water and stone rolled down is equal to that of a railway-train. At the foot of the cañon the sides come very close, and for seven miles the water goes along at the rate of 40 miles an hour. The rocks cut through by this force show all the geology of the country. Sometimes the face of the precipitous sides of the cañon is red, from a sandstone without a seam; or they may be of limestone—pink, brown, grey, slate-tint, and vermilion in colour, and polished to perfection. In the Grand Cañon, the highest sides are 6,233 feet above the stream, but they are only perpendicular for about 3,000 feet, where, indeed, the gloomy chasm is often but a few hundreds of feet wide. Above that, the sides slope off by a series of cliffs to the level of the surrounding country; and if the world lasts long enough, and a greater rainfall should come, a deep and wide valley will exist there some day or other.

Fig. 5.—Cañon, Colorado.

On looking at a map on which the cañons are traced, or at a bird's-eye view of the country in which they are found, one is struck with their position in regard to some mountains, and to their occasional rather zig-zag course. Some cañons form long lines close to the flank of the mountains, and just where the hills spring from the plain, and then they start off right away, and only bend here and there. The impression is given to the mind that some cracks in the earth had occurred to determine the path of the future water-course, which in time was to become a cañon. But if this were so, the crack did not displace or let down one side of the country around, so as to produce what geologists call a fault, for the levels of the layers of earth or strata, seen on each side of the cañons, correspond in a remarkable manner. It is generally

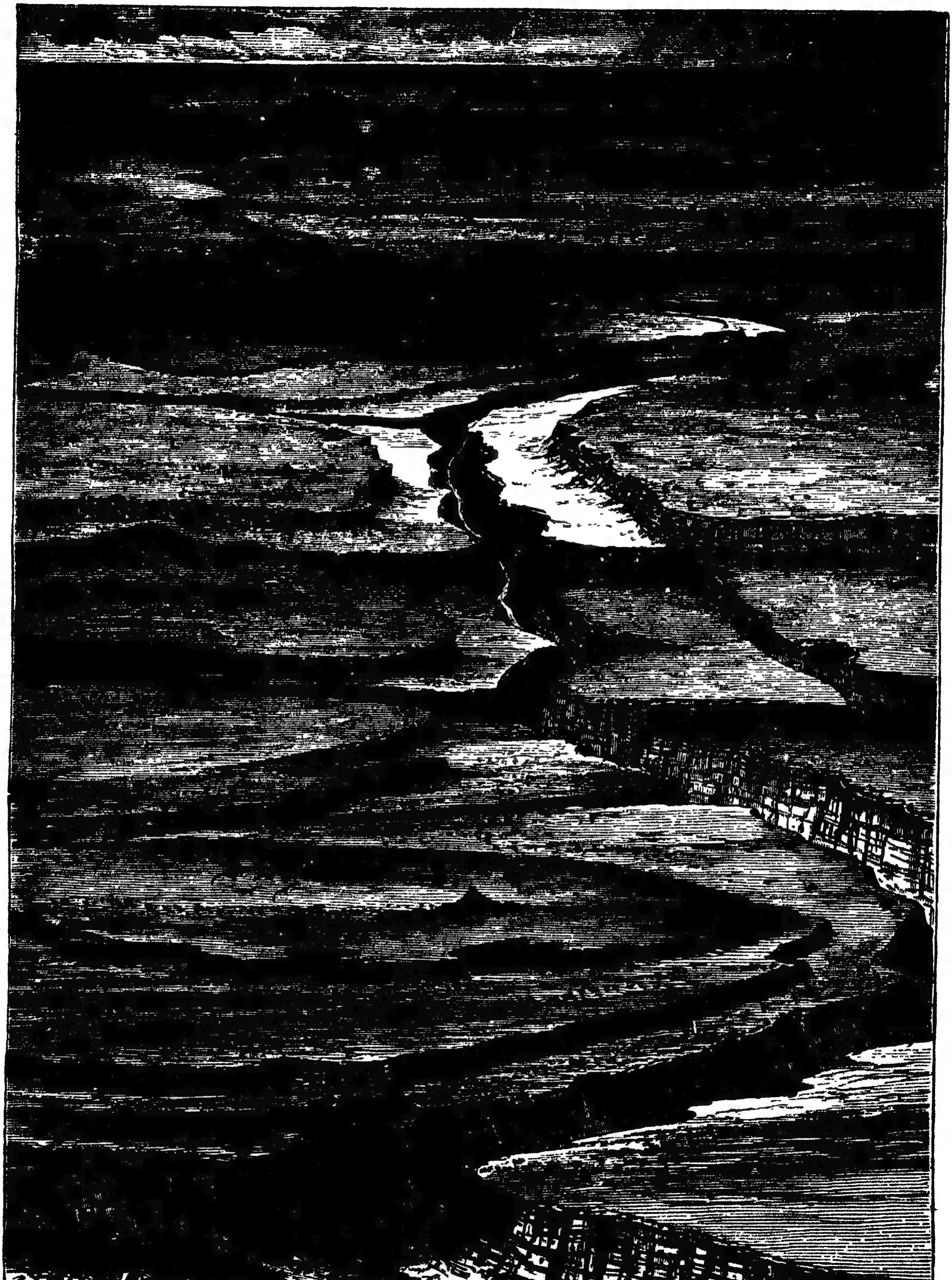


Fig. 6.—Bird's-Eye View of the Colorado Cañons.

found that wherever limestone is the top layer of the country, or nearly so, the wandering of the cañon is great. It is so easily worn by water, that if a hard piece resists for awhile the effects of a stream, the water will erode on one side of it, and then the course is diverted from the previous direction. Once made, the crack is deepened, and then other strata beneath it are worn down.

The word "Cañon" is applied in America to any gorge through which water flows, but, properly speaking, the term should be restricted to the long chasms with steep sides in nearly rainless regions.

# FRESH AIR AND FOUL AIR.

By Professor F. R. Eaton Lowe.

FRESH air is an element upon which everybody professes to set a high value; yet we frequently meet with people who, by dint of green-baizing the doors, sand-bagging the windows, stuffing up unused chimneys, pertinaciously closing the windows of a railway-carriage during a two hours' journey in July, and other similar expedients, endeavour to exclude the pure breath of heaven as they would so much choke-damp or sewage fumes. In these days of scientific progress it is surprising that so much ignorance exists on the subject of ventilation; for, while the terms "oxygen" and "carbonic acid" are familiar to everybody, most of us are still in the dark as to the best means to be adopted for securing the one and getting rid of the other. Those who take so much trouble in stopping up every crevice, to prevent, as they say, the ingress of "draughts," never dream that they are at the same time taking every precaution against the escape of poisonous gases, the inhalation of which must ultimately produce a train of disorders, the mere catalogue of which would fill a page of a large-sized medical treatise. Ventilation, as it is understood by such persons, includes amongst its happy effects, cold in the head, sore throat, toothache, and tic-doloureux, all of which may certainly be produced by draughts; but this is not ventilation. Much of this misconception is due to the ignorance of builders, who appear to think that ventilation is altogether out of their line, and consequently make no provision for it. In large public buildings—as schools, churches, and clubs—some attempt is usually made to keep the contained air pure; but in ordinary dwelling-houses there is nothing for it but to open the windows, at the risk of entailing upon delicate or non-acclimatised inmates the painful disorders just alluded to. It is far more important to secure a constant supply of pure air in rooms we ordinarily inhabit, than in public rooms only occasionally visited; and architects as well as builders have much to answer for in ignoring this consideration in the construction of their plans.

Before this subject can be thoroughly understood, it will be necessary to get a clear view of the function of respiration. We all of us are familiar with the appearance of the lungs of animals, from the specimens hung up in the butchers' shops. An examination of the lungs of a sheep will answer our purpose quite as well as if we had the corresponding organs of the human body before us (Fig. 1). They consist of two lobes of spongy, cellular matter—the spongy character being due to millions of minute bag-like air-cells communicating with fine tubes, the diameter of which gradually increases till they finally converge into the windpipe. The small air-cells are surrounded by meshes of delicate blood-vessels, still more minute, which bring the dark venous blood to the lungs to be oxygenated or purified, whence it is collected by the pulmonary artery and distributed to every part of the system. It may be asked, How is this oxygenation or aëration effected? Does the blood enter the air-cells, and come into actual contact with the contained air? Certainly not, or otherwise the blood would find its way into the windpipe, and be coughed up. This bleeding from the lungs, or hemorrhage, as it is termed, actually occurs in certain diseases, as in pulmonary consumption, and is a symptom of a very serious character. Instead of the blood finding its way into the lungs, the air permeates through the thin walls of the cells and comes in contact with the blood in the microscopic veins. Here important chemical changes take place, and both the air and the blood become entirely altered in character and composition. The dark appearance of venous blood (blood from the veins as distinguished from arterial blood) is due to excess of carbonaceous matter; the oxygen of the air unites with the carbon and becomes carbonic-acid gas, which is exhaled, and cannot again be

respired with safety, while the colour of the blood is changed to a bright red, indicative of its healthy character and fitness for all the purposes of nutrition. The number of respirations per minute varies from fifteen to twenty-one, according to age and constitution, and the quantity of air taken in at each inhalation is about twenty cubic inches. The carbonic acid comes off from the lungs in company with watery vapour, particles of effete or worn-out matter, nitrogen and other gases. Bad breath is attributable in some cases to caries or decayed teeth; in others, to the condition of the stomach; but in many instances it may be traced to the presence of fetid vapours in the expired air. We are in a condition of constant decay, or rather disintegration; worn-out particles are momentarily being cast off, and their places supplied by new matter; and while some of these particles of decayed matter escape through the skin and other channels, more or less of them are eliminated through the lungs, and find their way into the air.

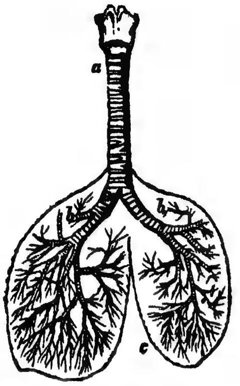


Fig. 1.—(a) Position of Larynx or Organ of Voice; (bb) Bronchiæ or Bronchial Tubes; (c) Position of Heart between the two Lungs.

Let us now examine the carbonic-acid gas, which —"carbon dioxide" of modern chemists—forms about one-thirtieth of the volume of air exhaled. The poisonous nature of this gas is pretty well understood, although its presence in our bed-rooms and sitting-rooms is little guarded against. It forms the choke-damp of coal-mines and deep wells, and, breathed in a state of purity, causes death in a few minutes by suffocation. It is a non-supporter of combustion; and flame is extinguished by it as completely as by the employment of so much water. advantage is taken of this property of the gas to detect its presence in deep wells which have to be descended for the purpose of repairs.

A candle is let down, and if it goes out it is at once concluded that it would be unsafe to allow men to descend. From the absence of this simple precaution men are frequently brought up from deep wells in a state of insensibility; and colliers are often exposed to similar risk from a sudden rush of large volumes of choke-damp from the workings (pp. 9, 22).

Another peculiar property of the gas is its weight. It is half as heavy again as air; the specific gravity of the latter being taken as 1, that of carbonic acid is 1·5. On this account it can be poured out of one vessel into another like a liquid. A row of lighted candles may be extinguished one after another by pouring upon each some carbonic acid; and as the gas is invisible, the experiment savours very much of the magical in the eyes of those unacquainted with chemistry.

The process of preparing this gas for experiment is very simple, and the necessary apparatus can be made from a couple of bottles and a glass tube. Take a wide-mouthed bottle fitted with a cork, and into the cork insert a glass tube, bent twice, at right angles, one limb of the tube being much longer than the other (Fig. 2). Into the bottle put some hydrochloric (muriatic) acid, diluted with a similar quantity of water, and into the mixture drop a few pieces of chalk, or limestone. A brisk effervescence will ensue, caused by the escape of the carbonic acid in bubbles from the chalk. The long end of the tube is inserted into another bottle, which will soon be filled with the gas. To ascertain whether the bottle is filled, put in a lighted match or taper, which will be extinguished as soon as it reaches the surface of the gas.

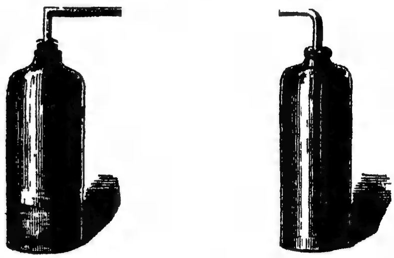


Fig. 2.—Preparation of Carbonic-Acid Gas.

By this experiment the chalk or limestone is decomposed, and carbonic acid set free; but by a very simple process we may cause the carbonic acid to unite with lime, and thus form carbonate of lime or chalk. This is the reverse of *analysis*, and hence termed *synthesis*. Nothing more is necessary than to fill a tumbler with lime-water—which can be procured at any druggist's shop for a trifle—and to blow into it through a tube, when a milky cloud will be immediately observed, owing to the formation of a white precipitate of carbonate of lime. This results from the union of the carbonic acid in the breath with the lime held in solution, and proves beyond question the existence of carbonic-acid gas in the exhalation from the lungs.

Besides being a product of respiration, carbonic

acid is also a product of combustion. The materials we usually employ for the purpose of illumination—as gas, tallow, oil, and coal—owe their inflammability to the presence of hydrogen. As this gas is in a state of combination with carbon, these bodies are known as *hydrocarbons*, and during combustion they undergo decomposition. The carbon unites with the oxygen of the air to form carbonic acid, and the hydrogen unites with another portion of oxygen to form water, which exists as steam or vapour in the air of every room in which flame of any kind is burning. To prove that the formation of watery vapour is one of the results of combustion we have only to invert a tumbler over the flame of a candle, when the inside will soon become moist from the condensation of the resulting steam.

It thus appears that the two processes of respiration and combustion are strictly analogous, so far as chemical change is concerned; and it follows that the air of a room is as much vitiated by the burning of a jet of gas or an oil-lamp, as it is by the breathing of an occupant. A flame cannot live without a renewed supply of fresh air, any more than an animal. Put an inverted tumbler over a taper, and in a few moments the flame will be extinguished. Effectually exclude the admission of air into a room, and the fire in it will first begin to get dull, and ultimately go out altogether. What is fatal to combustion is also fatal to human life; for respiration is a species of combustion, attended with the usual phenomenon of heat, and requiring for its support constant supplies of good fuel. The greater the proportion of fuel—that is, fresh air—consumed by the lungs in a given time, the more rapid is the respiration, and the greater is the heat developed. We are all of us familiar with these phenomena as the results of vigorous exercise in the open air. The glow in the cheek, the increased appetite, and the general exhilaration, are so many signs of intensified chemical action and increased vitality. Diminish the supply of fuel, or deteriorate its quality by constantly breathing the atmosphere of some close room or stuffy office in a back street for eight or ten hours daily, and the respiration will become slower, the heat of the fire will diminish, the colour will leave the cheek, the appetite will fall off, and the system generally will become debilitated.

We have said enough of the properties of carbonic acid to convince any one of the danger of breathing it, even in the diluted condition in which it exists in an ill-ventilated apartment. The question now is, How are we to avoid it? To escape from an enemy, we must know exactly the position it occupies. It has been stated that carbonic acid is a very heavy gas; and it might be supposed that it would fall to the floor as it is generated from the gas-burners, and the lungs of individuals. Immediately on its formation, however, it is in a heated state, and, in accordance with a universal law of heat, becomes much expanded, and rises to the ceiling. Should there be no means of escape in that direction, the gas will, on cooling, descend along the walls of the apartment, as shown by the arrows in the annexed diagram (Fig. 3), representing the atmospheric currents in a room lighted by three gas-jets and warmed by a fire in an ordinary grate.

The horizontal arrows at the base of the diagram

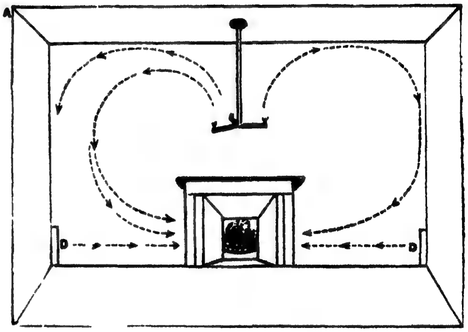



Fig. 3.—Atmospheric Currents in a Room.

represent the currents of air proceeding from the doors D D towards the fire. It will be seen that the cooled carbonic-acid gas as it descends along the walls is similarly drawn to the fire, and escapes up the chimney in company with the smoke and other products of combustion. Had a grating or ventilator been placed at the top of one of the walls, as at A, the deleterious exhalations would have escaped, and the air been preserved in a fit state for respiration.

A fire is an excellent missionary in the cause of ventilation, especially in a room where the green-baize and sand-bag processes have not been adopted to ward off the hated "draughts." The air withdrawn from the room to feed the column constantly rising above the fire, must have its place supplied by fresh air from without; which accordingly works its way through every crevice and opening, and makes at once for the heated laboratory where its decomposition is effected. A glance at the diagram will make it plain that if there is no ventilator near, the carbonic acid must be respired in its progress towards the fire by persons sitting in the

room, unless their dimensions are so Lilliputian that their heads are below the level of the grate. In the absence of any proper provision for ventilation, our only resource is to open the windows an inch or two at the top. This will effectually get rid of poisonous exhalations, without subjecting any one, not sitting immediately beneath, to the risk of "catching cold."

In bed-rooms, where we remain eight or ten hours at a time, it is most important that the escape of vitiated air should be provided for. On the assumption that the sleeping-apartment is occupied by only one person, who requires 20 cubic inches of fresh air at each respiration, or, on an average 400 per minute, in 10 hours he would consume more than 130 cubic feet of air —that is, if he could get it. But how? There is no ventilator; the door is kept shut all night; and as for opening the window but a single inch at the top—the very thought is enough to produce a shudder. Let any one who has been out in the open air enter a bed-room from which the sleepers have just emerged. The oppressive, not to say sickening, character of the atmosphere will at once make itself apparent. And yet people in general do not know to what cause to attribute their morning headache, their lassitude and debility, their loss of appetite, and the impurity of their blood, so plainly evidenced by numerous pimples and blotches. As a rule, our sleeping-chambers are much too small; ten feet square is not an uncommon size for one of these rooms in a house letting at £50 a year. The air of such a room, having its doors and windows closed, and occupied by one person, would become unfit for respiration in four hours. In the case of two occupants, that time would, of course, be reduced to two hours.

It is to be feared that we shall never be able to secure rooms of much larger dimensions, especially in the houses of great cities; it is, therefore, of the highest importance that the introduction of ventilators by builders should be made compulsory. In the meantime, it is easy to improvise a remedy against the atmospheric stagnation and pollution so common in our dwellings. Keep the doors of the rooms partly open, and let down the windows about an inch at the top. There is very little risk in such a procedure, even in tempestuous weather, except to persons who are so frightened at contact with cold fresh air that they are accustomed to wrap themselves up like a Greenlander whenever they are unfortunate enough to be compelled to leave their almost hermetically sealed abodes.

From what has been already said, it will be gathered that a room cannot be properly ventilated by opening a window at the bottom; and to sit for any length of time near a window opened in this way is not unattended with danger. The expense of inserting a ventilator in the upper part of the wall of a room would not be great, and the money would certainly not be thrown away. It should be constructed with oblique bars placed in such a way that the currents of air would enter the room in an upward direction, and no draught would be occasioned. In theatres and other public buildings of a circular, oval, or horse-shoe form, a central ventilating shaft answers very well. In oblong buildings a shaft at each end is necessary. Fresh air must be admitted through gratings at the bottom of the walls, as it is highly dangerous to open windows or doors where there are crowded assemblies.

In concluding this paper, a reference to the ventilation of mines may not be out of place. The *modus operandi* of a fire in setting up atmospheric currents has already been explained. The accompanying diagram (Fig. 4) shows the method of ventilating a mine by means of a furnace placed at the bottom of a shaft at D. The air is drawn into the mine in the direction of the arrows down the shaft A, and, becoming heated in its passage over the furnace, escapes from the mine up the shaft B. The "drawing in" of the air in such cases is simply an effect of pressure. Air is a fluid, and if any por-

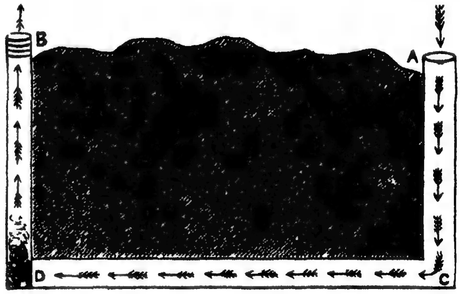


Fig. 4.—Ventilation of a Mine by a Furnace.

tion of it be displaced, as by heat, the surrounding portions must simultaneously fall in to supply the loss. The ascending column of hot air will carry with it all noxious gases and exhalations, and the atmosphere of the mine will be preserved fit for respiration. In spite of this precaution, however, miners are exposed to much risk from the sudden evolution of carbonic acid and carburetted hydrogen gases from the workings. The latter is the well-known "fire-damp," and inflames with explosive violence when a light is brought into contact with

it. The "Davy" lamp is a sufficient protection against this formidable enemy; and its invention has saved the lives of thousands. The safety-lamp, however, will not render the fire-damp respirable; when its existence is indicated, an escape must be effected with all possible expedition. The same course must be followed in the case of "choke-damp," or suffocation will speedily ensue. The aim of colliery proprietors should be to provide ready means for the elimination of these terrible scourges of the pit. If the distance of the ventilating-shaft from the workings is too great, the draught becomes so sluggish that the gases cannot be carried away. Additional air-shafts ought then to be constructed; and although the expense would doubtless be heavy, the safety of men engaged in so hazardous an employment ought to be the first consideration.

The subject of ventilation altogether is one which deserves more of the attention of social economists than it has hitherto received; for, while we can hardly attach too much importance to questions relating to cottage architecture, water-supply, and general drainage, it must not be forgotten that there is such a thing as atmospheric drainage, which is none the less important because unseen, and due provision for which is one of the most essential requirements for the maintenance of the public health.

# OCEAN SIGN-POSTS.

By Edmund Hope Verney, Captain, Royal Navy, F.R.G.S., F.R.A.S., etc.

Have you ever stood on the quay of a busy port, and watched the ships being hauled out to the pier-head, and then seen the white sails dropped and spread to the wind, and the vessels borne out far away into the distance?

Have you ever stood on a high cliff, with only the wide expanse of sea before you, and seen a little speck on the horizon, which you knew to be really a great ship on her voyage?

Or have you ever made a voyage yourself, and known what it is to see nothing around but sea and sky, while your own gallant ship is confidently and steadily bearing you on your way?

And if so, have you not longed to know *something*, be it ever so little, of the science of navigation, which inspires the sailor with the light-hearted confidence with which he leaves behind him every landmark, and sails straight away on a pathless sea? To sketch lightly the general principles of that science is the object of this paper; to give the reader such a general view of the subject that the craft of the seaman may not appear an incomprehensible mystery.

If you take ever so short a passage in never so small a steamer, two edicts of maritime law are imperiously thrust upon you: you must not smoke abaft the funnel, and you must not speak to the man at the wheel. With the former of these laws this paper has no concern, but the latter is founded on the first necessities of navigation. The man at the wheel is the guardian of the compass—even its servant. Unless otherwise directed, his eyes may hardly ever leave it. The ship is to be steered on a particular course shown by the compass; he must not forget that course, or mistake it; his thoughts and attention to it may at no time be relaxed. Only by vigilance and experience can he steer the ship on the given course. The "compass true" lies at the root of the sailor's confidence; and, as he leaves behind him every tower, every hill, and every lighthouse, to journey on an unmarked plain of waters, he knows that his compass will never fail him on the darkest night or in the foggiest weather.

But it is not enough for us to know only the direction in which we are going; we must also be able to measure the distance we travel. We know that if we leave this country, and steer westwards, we shall some day come to America; but if we would avoid being wrecked upon its shores, we must know when we are getting near them, and make our arrangements to enter a secure haven; and so from hour to hour we estimate the speed of our ship by what we call the "log." We have a coil of string wound upon a reel; the end is tied to the log, which is a small piece of wood shaped and balanced to float steadily in the water; the log is thrown overboard, and we note the time that a measured length of string takes to run off the reel. This, of course, depends upon the speed of the ship, and by a very simple computation the number of miles per hour may be estimated. The measured distances on the log-line are marked by knots; the time bears the same proportion to the hour as the knot does to the nautical mile, and hence we speak of the ship going so many

knots an hour; this estimated speed is written down in a book called the "log book," which is in fact the sailor's *journal;* for there we also write down the force and direction of the wind, the state of the weather, the course steered by compass, the nautical events of each hour of the voyage, all ships or land seen, and the changes made from time to time in the sails. Each day at noon the distance run in the previous twenty-four hours is added up, and applied in the direction that has been steered by compass; and we so ascertain what progress has been made in the voyage. This method of navigation is called by seamen "*Dead Reckoning.*"

Navigation by dead reckoning is comparatively simple and easy, and may often be relied on for short distances; but there are causes which make it untrustworthy. In different parts of the world are currents of varying strength, some running as fast as seven miles an hour. A captain may be steering west on his way to America, with fine weather and smooth water, and enter a current of sea-water many miles in width, running rapidly to the northward; there is nothing in the appearance of the sea to tell him he is in such a current, and if he has only his dead reckoning to trust to, he may be wrecked on the coast of Newfoundland at a time when he thinks himself 500 miles away from the nearest land, and 1,500 miles from New York. Or a strong southerly wind acting always on the side of a vessel will drift her bodily to the northward, although the steersman may keep her head pointing west. Or a ship may be so drifted about, and twisted and turned by stormy weather and changeable gales, that the dead reckoning may be entirely muddled and lost. Then we rely for our safety on the branch of navigation that is called "*Nautical Astronomy.*"

All who have made a sea-voyage must have observed the captain come on deck in the morning, and again at noon, in fine weather, with his watch in his hand, and a curious-looking instrument, called a *sextant,* at his eye, and, looking in the direction of the sun, make notes of what he observes. He is taking observations of the sun, to enable him to determine the position of the ship.

But before we can at all understand how he does this, we must first see what is meant by "the position of the ship." There are no marks on the sea to show us where we are, even although we have a map. Before us

> "Gleams that untravelled world, whose margin fades
> For ever and for ever as we move"

And so we rule our chart with imaginary lines crossing each other, and dividing the blank spaces of the sea into little squares; if we can tell which square we have got into, and to which part of it, we shall be able to see on the chart what progress we have made on our voyage. The lines running east and west mark the degrees of *latitude,* those running north and south the degrees of *longitude;* only when a sailor knows his latitude and his longitude can he determine the position of his ship. If you hold in your hand a clay ball of uniform colour, you cannot measure the position of any point on it, because there is no starting-point to measure from; but if you run a long needle through the middle of it, you at once get two starting-points—namely, where the needle goes in, and where it comes out. Such a ball is our earth; the north and south poles are its only two natural fixed points; the circumference of the earth half-way between the poles is called the *equator;* the lines of latitude are those parallel to the equator, and we count 90 degrees of latitude from the equator to the pole. The equator is obviously the most natural line to start from, and sailors of all nationalities count their latitude from thence. The lines of longitude are at right angles to those of latitude, but there seems to be no natural reason for beginning to count our longitude from any one place in particular rather than another; so the French count theirs from Paris, the Russians from St. Petersburg, and we count ours from the meridian of Greenwich. We choose Greenwich, because it is where our national observatory is, and to Englishmen it is the centre of all astronomical calculations.

To determine the position of the ship, let us first consider how the latitude is found at sea. The sun at noon in our northern hemisphere is always seen due south of us; if we sail away towards it, we shall find it gets higher and higher every day at noon, until we get near the equator, when at twelve o'clock it will be exactly over our heads, and we shall have no shadow whatever; or, if we sail northwards, the sun sinks lower and lower, until in polar regions the sun is sometimes only on the horizon at noon. The sextant is an instrument for measuring angles, and when the captain comes on deck at noon it is to measure the height of the sun above the horizon. He begins to observe a few minutes before twelve, and watches it slowly rising, until at last it stops and slowly begins to descend; the highest altitude that has been observed gives the latitude by a very short calculation, in which the chief element to be considered is the position of the sun itself with reference to the

equator. Only twice in the year is the sun exactly over the equator—namely, at the equinoxes. In summer it comes much nearer to us, and in winter it goes much farther off. Its distance north or south of the equator is called its *declination*, and the path it appears to follow, crossing and re-crossing the equator, is called the *ecliptic;* therefore, if we did not calculate the declination with the altitude, we should get only our distance from some point on the ecliptic, instead of our latitude, which is our distance from the equator. There is annually published a book called the "Nautical Almanac," prepared at the Greenwich Royal Observatory, in which all the movements of the sun, moon, planets, and principal stars have been calculated beforehand. From this book the sailor gets the sun's declination, corrects it for the moment of noon at which he took his observation, and so is able to derive his latitude.

It often happens that the sun is obscured by clouds at noon; but we can get our latitude at night on the same principle from a meridian altitude of the moon, of a planet, or of a star. There is also a method called "double altitude," which consists in estimating, from two altitudes of a heavenly body *not* on the meridian, what must be its altitude when it *is* on the meridian.

But there is still another method of finding the latitude, which is doubtless the oldest of all; that is, by an observation of the pole star. Centuries ago, it was observed that all the stars and all the heavenly bodies appeared to revolve round one star always north of us, and apparently fixed and motionless; *now* we know that it is the earth that revolves, and that this fixed star, which we call the pole star, is almost vertically over the north pole of the earth. A man standing at the north pole would have this star exactly over his head; a man standing on the equator might see it exactly on the horizon; and so, wherever you are in the northern hemisphere, the height of the pole star above the horizon is always the latitude of the place you are in.

By one or other of these methods the seaman finds his latitude, how far he is from the equator; but to know the position of his ship he must also know his longitude, and to find this is not nearly so simple a matter. As the sun appears to rise in the east, it must be daylight in Denmark before it is in England, and in Russia before it is in Denmark; so also is it noon first at St. Petersburg, then at Copenhagen, then at London; so when it is noon at St. Petersburg it is only about eleven at Copenhagen, and about ten in London. The greater the difference of longitude, the greater the difference of time between any two places. The two questions of time and longitude are so intimately connected that they may almost be said to be identical. The globe is divided into 360 degrees of longitude, which are all passed over by the sun in the course of twenty-four hours—that is to say, 15 degrees in every hour. If, therefore, we know that there is one hour's difference of time between London and Copenhagen, we know that Copenhagen must be 15 degrees, or 900 miles, distant. If, then, a ship is in the Atlantic at exactly twelve o'clock, and the captain knows that it is at that moment exactly one o'clock at Greenwich, he knows that he is 15 degrees west of Greenwich, and that that is his longitude.

Therefore, in order to find our longitude at sea, we require to know two things: *First*, the time, exactly, to a second, on board the ship; and, *secondly*, the time at the same instant, and as accurately, at Greenwich. Great accuracy is indispensable, because, if one hour of time corresponds to 15 degrees of longitude, a mistake of one minute will make a difference of 15 miles in the position of the ship.

The exact time on board ship is found by an observation of the sun, usually taken at eight or nine in the morning, when it is rising rapidly. This observation, with somewhat intricate mathematical calculations, gives accurately the time which would be roughly shown by a sun-dial. It is then only necessary to know with the same accuracy the time at Greenwich at the instant the observation was taken; and by comparing the two times, we at once get the longitude. This Greenwich time may be found in various ways, but the simplest is to carry on board the ship a clock which was set to London time before the ship sailed. Such clocks are specially made to go correctly and evenly in all climates, and by ingenious contrivances they are compensated for changes of temperature. They are called chronometers. A large ship carries several chronometers, that by comparing them one with another, a more accurate Greenwich time may be arrived at. They are hung in swinging cradles, that they may not feel the rolling of the ship; even the cradles are supported from a foundation of tow or wool, that they may not suffer from any shock or jar. The chronometer-room is placed in the middle of the ship, and is kept, as far as possible, at a uniform temperature. Chronometers are made to go for two days without being wound up, but it is usual to wind them up daily, in case of accidents. In a man-of-war, the sentry at the captain's cabin door is not relieved in the morning until it is reported to him

that the chronometers have been wound up; and if he is thus retained at his post beyond his proper term of duty, he takes good care to make it known that the chronometers have not yet been wound up. The chronometers are all compared one with another every day, and a register is kept of their performances, from which it is at once seen which are going most steadily, and can most surely be relied upon. When a ship makes a long voyage, the Greenwich time shown by the chronometers is carefully tested whenever she arrives in a port whose longitude is well known. We see, therefore, of how vast importance to the sailor is his chronometer, as affording his readiest means of knowing Greenwich time.

*But it is only within the present century that the workmanship of chronometers has been so far perfected that the sailor can safely rely on them. formerly, he got his Greenwich time from observations* of the moon, difficult to make, and requiring long and intricate calculations to arrive at the result. All who read this paper will be aware how rapidly the moon changes her place among the stars, how each night she makes her appearance farther to the eastward than the night before The "Nautical Almanac" tells us exactly for every hour throughout the year what will be the moon's place among the stars. Suppose we read that when the moon's edge touches a certain star it will (at Greenwich) be exactly ten o'clock on a particular night; in whatever part of the world we are, all we have to do is to watch the moon until this contact occurs, and when we see it we know that it is just ten at Greenwich, and so we get the Greenwich time to compare with the time on board the ship. We may compare the starry heavens to the dial, and the moon to the hand which points out time, to all who can read that mystic clock. The early navigators of the last century depended for their longitude entirely on lunar observations.

The Greenwich time may also be found by observation of any marked event in the heavens, as, for instance, by observing the moment when one of Jupiter's satellites disappears behind the planet, the Greenwich time for which will be found in the "Nautical Almanac."

When the latitude and the longitude have been ascertained by trustworthy observations, that latitude and longitude are accepted as true, however much they may differ from the results afforded by the dead reckoning, and the position of the ship is marked on the chart according to these observations. The difference between the observed position of the ship and the position indicated by the dead reckoning is full of interest. It is probably due to a current which has drifted the ship in one direction, but it may be due to the leeway made by a ship under sail, and insufficiently allowed for in the log; or it may result from careless steering, or from inaccuracy on the part of the officers whose duty it has been to write up the log. The principal ocean currents are now so well understood that no captain ought to accept a current as the explanation until he has satisfied himself that the difference is not due to some other cause. In iron ships the difference may be due to a deflection of the compass over and above its known deviation. This deviation is carefully ascertained for each point of the compass before the ship leaves port, *and a table of* deviations is supplied to every ship, whether she be built of wood or iron; but a change in the cargo of a ship may affect the compass, or a different distribution of any iron on board; even the knife in the steersman's pocket has been known to affect it, and it is well every day to compare the compass-bearing of the sun or some other heavenly body with its true bearing, ascertained by calculation, to see whether the deviation-table still remains correct.

These are the methods most generally in use among seamen, when far out at sea in blue water; but the use of the lead and line, when nearing land, deserves some mention in this paper. Many parts of the sea have been so carefully surveyed that not only is the depth of water marked in the chart, but even the nature of the bottom of the sea, whether it be rock, or sand, or shells, or clay, or mud. Specially and elaborately has the British Channel been surveyed, and in foggy weather, when neither sun, moon, nor star is visible, the seaman can confidently grope his way up Channel, trusting to the lead alone. There is a cavity filled with tallow at the bottom of the leaden plummet; the lead line is marked at every two or three fathoms, and when the depth has been ascertained by the line, the lead is drawn up to the surface, and the nature of the bottom known by the marks on the tallow. Three or four casts of the lead will determine with certainty the position of the ship. If, for instance, the first cast of the lead shows 30 fathoms of water, and a sandy bottom; the ship runs a mile east and then gets 28 fathoms, with sand and shells on the bottom; the ship runs a mile farther, and a third cast of the lead shows 27 fathoms, with a bottom of broken shells; the probability is that there is only one place in the British Channel where such a result

can be obtained; should there, however, be any doubt, a fourth cast of the lead would show the ship's position unmistakably.

But for ocean voyages, it is to the heavenly bodies alone that the seaman can look for guidance; he soon learns the names of the principal stars and constellations; they become his familiar and trusted friends; they speak to him a language which the landsman knows not. Evening after evening does he watch for their re-appearing as the daylight fades; and knowing exactly where to look, he discerns their first faint twinkle. From them he draws the imagery of his songs; the ideal of his earthly love is the pole-star, to which his heart points true as the needle to the north. When he thinks of his Poll or his Nancy watching for his return in the little village on the cliff, to which his heart so fondly turns, he sings—

> "Bright stars shall represent thine eyes,
> The spotless moon thy soul."

Amidst the ceaseless changes of winds, and waves, and weather, the stars, which to the landsman are merely beautiful objects in the night landscape, to a sailor bring a feeling of boundless confidence and security. They are ocean sign-posts of certain accuracy, fit types of Him "in whom is no variableness, neither shadow of turning."

## GEYSERS.

By Professor W. F Barrett, F.R S E., M.R.I A., etc

PERHAPS none of the grander operations of nature awaken more interest in a thoughtful mind than the two magnificent phenomena which form the subject of the present and succeeding papers—namely, Geysers and Glaciers. Every one knows that a *geyser* is a gigantic and intermittent fountain of boiling water, found not only in Iceland, where they are best known, but also in New Zealand, and on a vast scale in a district of North America known as the Yellowstone Region. The *glacier*, on the other hand, is a huge river of ice, slowly moving down a mountain side, perpetually melting in the warm valleys below, and as perpetually renewed by the snow-fields above. The present glaciers of Switzerland or of Norway are, however, very much smaller than those gigantic sheets of ice which swathe the interior of Greenland, and that once covered whole regions of this country and the Continent of Europe.* Not only do these phenomena, in their magnificence and ceaseless unrest, afford a sublime spectacle, but they appeal to the reason as well as to the sight. For the geyser tells us that beneath the ice-clad surface of the ground is a source of unquenchable heat, a hidden storehouse of tremendous energy; whilst the glacier speaks of a realm of perpetual cold that remains unwarmed though traversed by the rays of a tropical sun. Mankind, with all its appliances, cannot alter by the smallest fraction of a degree this inner bosom of heat nor this outer mantle of cold. Nevertheless, in the slow march of ages these conditions have changed, and still are changing, for the tendency of nature is towards uniformity. As the sea rounds the pebble on the shore, and strives to level the surface of the earth, so under the operation of time broad differences of temperature gradually disappear. Time is, in fact, a most pitiless communist. Thus, the extremes of heat and cold are less than once they were, and hence the glacier, and probably the geyser, of to-day are but as pigmies compared with the giants that were in existence in years long past. As if, however, to teach man the humbleness of his reason as well as the smallness of his strength, these ancient and impressive phenomena have as yet received but a partial explanation, and that only at the present day. This much, however, is evident to the most ignorant — in the geyser we have water boiling and boiling over; in the glacier we have water frozen and slipping down the mountain side. Out of the commonest of all things—water—we are presented with the most imposing of appearances and the most puzzling of physical problems.

To the geysers let us first address ourselves. The boiling springs of Iceland are better known than those elsewhere. They are situated near the great glacial plateau in the south-central part of the island, some score of miles from Hecla, and some 300 feet to 400 feet above the sea. The Great Geyser is the most conspicuous of the Icelandic group (Fig. 1). Observed at rest, all that is seen of this geyser, which may be taken as a typical one, is a saucer-shaped pool of hot water, contained

* "Science for All," p. 39.

in a smooth circular basin from 40 feet to 50 feet in diameter. In the centre of the basin is a tube nearly 10 feet across, and some 70 to 80 feet deep, and this, of course, is also filled with water, near its boiling-point. Within this tube lies the secret of the seething fountain that periodically bursts forth, *accompanied by vast clouds of steam, and with rumbling sounds and rattling explosions, causing the earth to quake for a considerable distance* around. The word geyser (pronounced "giser") is interesting account of an eruption, given by an eye-witness:—

"It was a grand display, and well worth all the waiting. Instead of ending suddenly or gradually, the steam salute shot faster and faster; thuds followed each other rapidly, and the whole ground shook; then the sound of dashing water and the music of waves was added to the turmoil. A great dome rose in the middle of the pool, and frequent waves dashed over the edge of

Fig 1.—The Great Geyser, Iceland.

derived from the Icelandic word *geysa*, "to be impelled"—that is, something gushing forth. It is commonly imagined that if one visits the geyser district, an eruption is sure to be seen within the course of an hour. But this is by no means the case—at any rate, so far as regards the display of the Great Geyser, which is the special object of attraction. Moreover, it is to be regretted that the intervals between the eruptions of this geyser are growing longer and longer. In 1770, the Great Geyser broke into eruption nearly every hour; in 1814, every six hours; in 1872, only once or twice a week; and now often a week is spent fruitlessly waiting for an eruption to occur. Here is an

the basin, while streams overflowed and drenched the whole mound. Great masses of rolling steam burst out of the water-domes, and rose in the still air, swelling like white cumulus clouds against a hard blue sky. At last the whole pool, 50 and odd feet wide, rose up, a single dome of boiling water, and burst; and then the column in the tube, 70 feet deep and 20 feet wide, was shot out of the bell-mouthed blunderbuss with a great burst of steam. The charge scattered; it rose about 80 feet, and most of it fell back and sank in with a rush; and so the glittering fountain rose thrice, like some mighty growth." *

* Campbell: "Frost and Fire," p. 413

The height to which the column of water is thrown has been variously estimated. The earliest records—a century ago—say 360 feet; but in modern times 100 feet seems to be the general opinion, and this has been confirmed by careful measurements made by competent observers.

Having thus obtained a glimpse of the phenomena attending an eruption of a geyser, we shall have more interest in searching for the explanation of these wonderful fountains. The clue to their mystery will doubtless be found in a careful study of boiling water. Water, when it boils, turns into an invisible vapour, steam. Incidentally we may remark that most people imagine steam is the visible cloud we see issuing from a kettle or a locomotive. But it is not so. True steam is quite invisible: the white cloud we see consists of water finely divided—a water-dust, as it were—and these impalpable particles of water are for a time suspended in the air by reason of their extreme lightness. Any one can easily illustrate this. Put a kettle on the fire, and let it boil vigorously, so that a good cloud of so-called steam issues from the spout. Now light a torch of paper, and hold it beneath the cloud near the spout. Instantly the cloud vanishes. The steam is there, but it is invisible. The heat has converted the myriads of fine particles of water formed by the cool air of the room into the perfectly invisible vapour of water, or

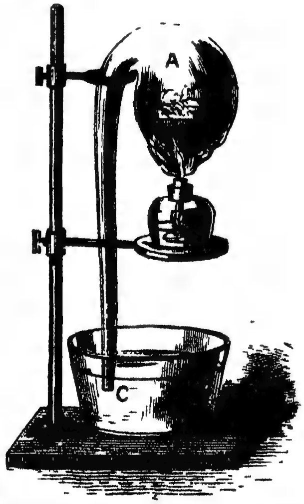


Fig. 2.—Showing relative Bulk of Steam to the Water whence it is derived.

true steam (p. 31). If we could see inside the kettle, as we can see inside a glass flask in which a little water is boiling, a space as transparent and invisible as air would occupy the interior. As, however, we have no word to designate the white cloud of partially condensed steam, we must understand the limitations under which the word steam is used when applied, as is usual, to the cloud of fine spray. Now when the water is converted into true steam, the latter occupies a volume 1,650 times as large as that of the water. This is easily remembered by observing that a cubic inch of water is converted into about a cubic foot of steam. A simple experiment will illustrate the large bulk occupied by steam relatively to the water whence it was derived. In the bulb A (Fig. 2) is placed some water, which is kept boiling by means of a spirit-lamp, and thus the upper half of the bulb and the tube A C are filled with steam. When the lamp is taken away, this steam is condensed by the cold water in the vessel C, which is observed to rise slowly in the tube till it has rounded the bend, when it rushes tumultuously into the bulb A, and fills it entirely with water. The steam has been condensed to a very small quantity of water, relatively speaking. An empty Florence oil-flask may be used for this experiment. Boil a little water within the flask. and then, whilst the water is boiling and the steam issuing from the neck, suddenly invert the flask in a basin of cold water. Up will rush the water, and fill the flask with a blow that sometimes drives the bottom right off. The condensation of the steam has made a partial vacuum in the bulb or flask, and the pressure of the atmosphere urges up the water below. This is the principle of Savery's early form of steam pump; for the water would also have risen if the tube had been any height less than 30 feet to 34 feet. A more striking experiment, illustrating the same fact, may be made with a tin canister having a narrow neck. In the canister a little water is boiled, and whilst boiling, the neck is corked. On pouring cold water over the canister, the sides are completely and suddenly crushed in. The cold water condenses the steam within, thus causing a great shrinkage of bulk, and consequent diminution of pressure; so that there is nothing to oppose the external atmospheric pressure, which crushes in the sides of the cylinder.

It is this largely augmented bulk given to the water, this elastic force imparted to it by heat, that drives the steam-engine, and which is evidently the motive force in the geyser. In 1812, Sir George Mackenzie, in his now classical work, "Travels in Iceland," proposed an explanation of the geysers founded on this principle. He imagined that the geyser-tube communicated at its lower extremity with some subterranean cavern, the neck of which

was contracted as shown in Fig. 3. These caverns, partially filled with water by percolation through the soil above, were, he supposed, heated by heat-

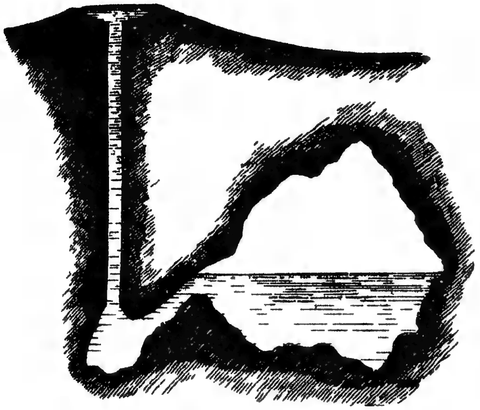


Fig 3.—Showing Geyser-Tube in communication with Subterranean Cavern

conducting rocks, which derived their warmth from the internal heat of the earth. The water would thus be boiled, and the steam so generated would accumulate in the space above the water until it gained an elastic force sufficient to blow the water out of the tube. Or, failing this, the steam escaping round the neck of the cavern by pushing the water before it, would condense in the cooler water of the tube. and thus cause merely a rising and falling of

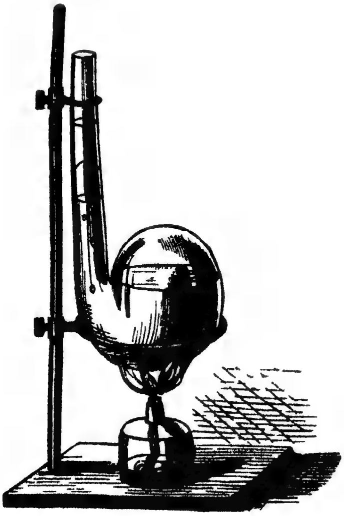


Fig 4.—Illustrating the "Cavern" Theory

the water within the basin above, as is seen in some of the geysers.

To illustrate this theory, we may partly fill an ordinary chemical retort with water, and, turning the neck upward, heat the bulb, which will represent the cavern, as shown in Fig. 4. As soon as the water begins to boil, the column of water in the tube is lifted up, steam escapes round the bend, the pressure is relieved, and the column subsides. By tightly corking the end of the tube, we may, of course, obtain an accumulation of pressure, which ultimately will blow out the water with a considerable eruption.*

Simple as is this explanation, and long as it has held its ground, it probably does not represent the true cause of the activity of the geysers. Fortunately for science, Robert Wilhelm Bunsen, the great German chemist, has given us a key which unlocks the mystery of the geyser eruption, without resource to any hypothetical subterranean cavern. Just prior to an explosion, Bunsen was able to take the temperature of the water at various depths in the geyser-tube. From these observations he was led to propound an ingenious and satisfactory explanation—one subsequently verified by Professor Wiedemann, who, guided by Bunsen's theory, constructed an excellent artificial geyser simply with a long, straight tube of water, heated at the bottom.

Let us now try to understand the nature of Professor Bunsen's theory, as it probably represents the true explanation of the geyser fountain. Under ordinary circumstances, water boils in an open vessel at a constant temperature, which is 212° upon the Fahrenheit thermometer, at the sea-level. However much heat we may supply to the water, it will get no hotter by continued or violent boiling, so long as the vessel remains uncovered. But the result is very different if a cover be put on the vessel and tightly fastened down. In this case the steam cannot escape, and thus the heat given to the water can no longer be carried away; the consequence is that the temperature rises above the ordinary boiling-point; and if we had a vessel strong enough, we might make the water as hot as molten brass. The high temperature that can be given to water under pressure, led to the invention of the "digester," which is commonly employed in the manufacture of soup and gelatine. On the other

* A modification of this cavern theory has been proposed by Mr. Baring-Gould. Mr. Gould suggests that a tube bent at an obtuse angle is all that is necessary; the water being heated in the sloping and shorter arm, steam will accumulate which will ultimately eject the cooler water from the mouth of the longer, vertical arm. A small model, Mr. Gould states, perfectly realised his expectations, but the present writer, having made a model after Mr. Gould's directions, has failed to obtain results at all analogous to the geyser eruption.

hand, if we lessen the atmospheric pressure which originally rested upon the surface of the water, it will boil at a temperature below the ordinary boiling-point. In fact, this is one way in which the height of mountains can be ascertained—by carefully noting the temperature of ebullition at various altitudes, for it is found approximately that the boiling-point of water is reduced 1° Fahr. for every 590 feet we rise above the sea-level. At the top of Mont Blanc, for example, the boiling-point of water is 185° Fahr. Beyond that point we cannot raise the temperature of the water in an open vessel, at this elevation. A simple and pretty experiment enables us to prove the dependence of ebullition upon pressure. If water be boiled in a Florence flask, the lamp removed, and the flask instantly corked, the water can again be made to boil by simply condensing the steam in the upper part of the vessel with a wet cloth. Condensation of the steam diminishes the pressure within, and the temperature of the water being above the boiling-point at this pressure, it enters into rapid ebullition, which can be renewed from time to time by afresh condensing the steam (p. 30). By inverting the flask we may use a block of ice to condense the superincumbent steam, and thus boil the water by the application of cold, as is shown in Fig. 5. It will be understood, of course, that the water, though boiling, is not so hot as if it were boiling in the open air. The following table shows at a glance the boiling-point of water at various places:—

| Name of Place. | Height in Feet. | Mean Height of Barometer | | Boiling point of Water. |
|---|---|---|---|---|
| | | | | Fahr |
| Mont Blanc . . . . | 15,790 | 16 5 | inches | 185° |
| Quito . . . . . | 9,541 | 20 7 | ,, | 194° |
| Mexico . . | 7,471 | 22·5 | ,, | 198° |
| St. Gothard . | 6,808 | 23·1 | ,, | 199° |
| Briançon . . . | 4,285 | 25·4 | ,, | 204° |
| Madrid . | 1,995 | 27·7 | ,, | 208° |
| Moscow . . . | 984 | 28·4 | ,, | 210° |
| Vienna . . . . | 436 | 29·4 | ,, | 211° |
| Level of the Sea | 0 | 30·0 | ,, | 212° |
| | Feet deep | | | |
| Bottom of a Lake . . | 34 | 60·0 or 2 atmos | ,, | 250° |
| ,, ,, Great Geyser | 77 | 3¼ | ,, | 280° |
| ,, ,, Artesian well | 1,000 | 29 | ,, | 453° (Tin melts) |
| ,, North Pacific *Challenger* sounding | 23,700 | 728 | ,, | 900° (Bronze melts) |
| Probable depth of parts of the ocean. . . . | 32,500 | 1,000 | ,, | 963° (Red heat) |

It should be noticed that as we descend in a mine the boiling-point of water is raised; and if the water could be made to boil at the bottom of an artesian well a thousand feet deep, the pressure of the superincumbent column of water, together with that of the atmosphere, would be equal to 29 atmospheres of pressure, and under such circumstances water would boil at a temperature of 453° Fahr. Calculated in this way, at the greatest depth of the ocean, water would be raised to a temperature of red heat before it would boil.

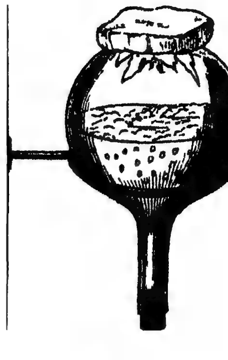


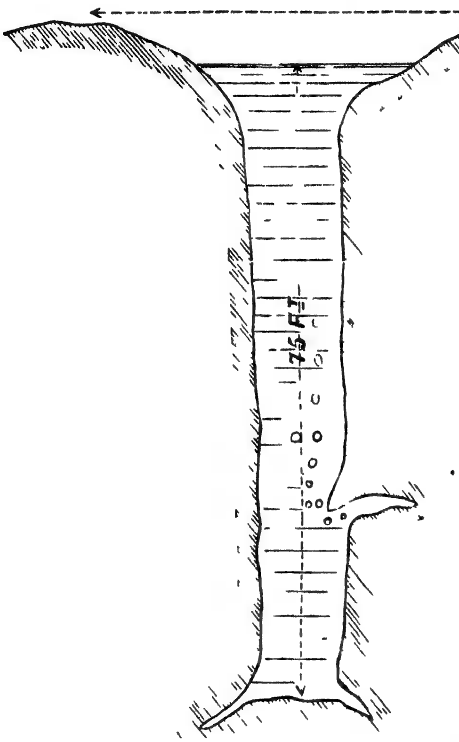
Fig. 5.—Illustrating the Dependence of Ebullition upon Pressure

We may now apply these facts to geyser eruptions. In the next diagram (Fig. 6) is given in section a view of the Great Geyser of Iceland, and by its side a series of temperatures carefully taken at the depths given in the first column.* In the third column is placed the calculated temperature at which the water would boil at those depths. In every case it will be observed that the actual temperature before the eruption was below the proper boiling-point for the particular spot. A ledge was noticed, in the soundings taken, not far from the bottom of the tube, and from under this ledge steam seemed to be issuing. Let us suppose that the temperature gradually rose to the theoretical boiling-point at this spot. Steam would then be formed, and would lift up the column of water to some extent; the pressure in the tube would thus be diminished by the water spreading into or overflowing the basin above. At 45 feet the water had a temperature of 251° Fahr.; even were this temperature not increased, but the depth merely reduced by the surface overflow to 36 feet, the water would be at a temperature above its boiling-point at this depth. For here it would boil at 250° Fahr., and the actual temperature is 251°. Having thus an excess of heat above its boiling-point, a sudden generation of steam would take place, which would eject the column of water overhead. Furthermore,

* These temperatures were taken by Mr. R. Walker. See "Proceedings of the Royal Society of Edinburgh," April, 1875.

the moment the pressure is diminished throughout the tube, the stored heat in the water below would generate large quantities of steam in the lower part of the tube, and the whole mass of water above, with the contents of the basin, would be hurled into the air amid clouds of liberated steam. The water, cooled by its eruption, and falling back into the basin, will be once more heated, and after a time again expelled, producing the periodic eruptions that are observed.

The construction of an artificial geyser, therefore, simply requires a long, straight, water-tight tube fixed into a basin overhead. It is convenient to heat the bottom of the tube with gas, and to imitate the heating a little higher up the geyser-tube by a spiral of gas-flames, fixed about a foot or so from the lower end of the tube. Fig. 7 shows the whole apparatus. The present writer has had tubes of various sizes made, and the following dimensions may be found useful. The large geyser shown in the figure has a tube of galvanised iron 5 feet 6 inches long, and $4\frac{1}{2}$ inches in diameter at its lower end, tapering to, say, $1\frac{1}{2}$ inches at the upper. It is convenient to make the tube screw into the basin, which is about 4 feet in diameter. The wooden supports rest in sockets in the basin, from which they can easily be removed; they are braced together to give rigidity. A smaller geyser may be made of a tin tube 3 feet long, $2\frac{1}{2}$ inches wide at the bottom, tapering to $\frac{3}{4}$ inch above, with a basin 2 feet in diameter.* The large geyser erupts periodically about every ten minutes, and the smaller one about every minute. The height to which these periodic eruptions rise is about 3 feet in the large tube and 1 foot in the smaller one. By corking either of the tubes, however, we may obtain a magnificent eruption of upwards of 30 feet high in the larger tube, and some 15 feet in the smaller one. This corking of the tube is but an imitation of what is actually done to provoke the eruption of a smaller geyser in Iceland, known as the Strokr, or "churn," an amusing account of which is given by Mr. Campbell in his "Frost and Fire":—"Strokr is a conical oval pit 8 feet wide at the top, and less than 6 inches wide near the bottom, 36 feet down. The water is always surging, growling, and frothing about within




| Depth in Feet | Observed Temperature | Calculated Boiling-point of Water at this Depth |
|---|---|---|
| 0 | 187° Fahr. | 212° Fahr. |
| 18 | 197 „ | 235 „ |
| 27 | 211 „ | 212 „ |
| 36 | 213 „ | 250 „ |
| 45 | 251 „ | 258 „ |
| 54 | 256 „ | 266 „ |
| 67 | 259 „ | 275 „ |
| 75 | 257 „ | 280 „ |

Fig. 6.—Section of Great Geyser.

* To Mr G. With, of Hereford, the writer is indebted for the results of a series of experiments with geyser-tubes of varying length.

6 feet of the top. By turning a barrowful of turf into this pit, this kettle is made to boil over; steam is stopped, the water is stilled for some minutes, and the wad is greatly heated below. Then a dome grows and bursts, and wad, and water, and steam from the gun are thrown up like a giant sheaf of

. 7.—Model of Geyser.

corn. First the water in the well makes a furious swirl, like an eddy from a stricken whale in shoal water; and then the column rises and overflows slowly, with increasing swiftness, till the dome rises up and bursts, to make way for a steam bubble as big as a balloon. Up go the projectiles, and down they come in showers and streams, to rise again with furious bursts; and woe betide the spectator who gets within range of this scalding spray."

Another traveller in Iceland (Captain Forbes, R.N.), who eighteen years ago published an interesting account of his travels in Iceland, describes how he made use of an eruption of the Strokr to cook his dinner, which he tied in a cloth and threw into Strokr, after administering what he supposed was a forty-minute dose of turf. "Seven minutes after time my anxiety was relieved by a tremendous eruption, and, surrounded with steam and turf-clods, I beheld my dinner in mid-air; down it fell close to the brink. The mutton was done to a turn."

But Great Geyser and Strokr are not the only, though they are the most notable of the boiling fountains in the geyser-district of Iceland. There is the active spring known as Little Geyser, which is perpetually tossing up jets of water to the height of 3 feet; its mouth, however, is only some 2 feet across, and its vertical depth not much more than 12 feet. "Close to the Little Geyser"—and here we quote from Mr. Baring-Gould's "Iceland: its Scenes and Sagas"—"is a puddle of black mud, presenting the most ludicrous appearance. It remained tranquil for about half a minute, and then a bell rose like a thumb, to the height of 4 inches, and sank back again, without bursting, scattering, throwing out steam, or making the slightest sound. I named it 'Jack-in-the-Box.' But Jack was not always so demure: on my choking the throat of the Little Geyser with turf, I found that the slime-puddle was converted into a jet of steam and inky water, which played with vivacity till the Little Geyser had relieved itself of its dose. South of these are some limpid pools, so hot that the hand cannot be borne in them for an instant. . . To the north, on the farther side of a scalding brook, is a noisy fountain, which may have played at one time to a considerable height when it was not choked with stones. Now the water only escapes in hot squirts, which fizz and growl among the encumbering fragments without the power of dislodging them.* Proceeding north-east from Little Geyser are several splits and holes in the incrusted floor which extends to the Great Geyser. Down them the water can be seen and heard, lashing and sobbing, whilst the steam blows off from the

* Mr. Gould here utters a protest, in which we heartily join him, against the mischief tourists do in choking the throats of these boiling fountains with stones. Turf does no harm, but stones are an indigestible bolus which often proves a fatal dose to a geyser.

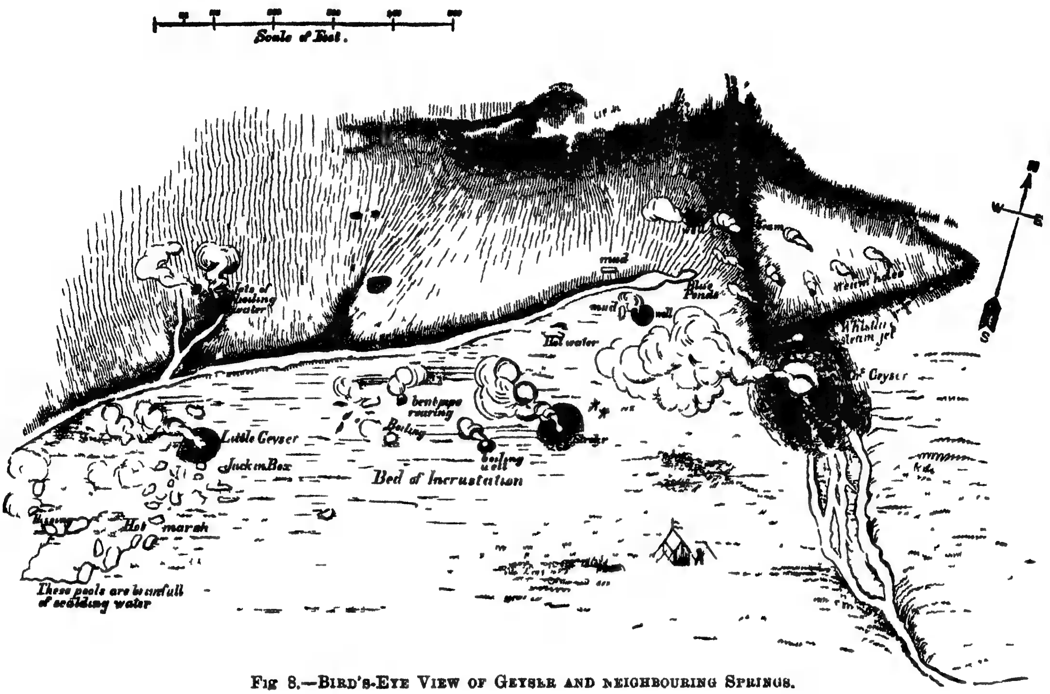



FIG 8.—BIRD'S-EYE VIEW OF GEYSER AND NEIGHBOURING SPRINGS.

orifices. The largest of these is a tunnel, with a bent pipe, so that the water cannot be seen, though heard roaring angrily in its den." Then, close to Strokr is a boiling well, and other hot springs of water and mud are near the Great Geyser, as shown in the above sketch-plan, from Mr. Gould's work (Fig. 8). Two lovely and deep pools of still blue water, connected by a stream not far from the Great Geyser, excite every traveller's admiration. Beautiful siliceous petrifications, of which we shall speak presently, are to be seen far down in the water, tinted green and blue, while the edge on which one stands shelves over the water. These pools are much higher than the Great Geyser and Strokr; there is, in fact, a range of 50 feet in the difference of level among the various springs and pools in the geyser district. The district itself is comparatively small —only some 440 yards in one direction, by 140 in another. Its position is peculiar; to the north a range of hills rises out of the plain, and south of them a volcanic rock—trachyte—has been forced like an island out of the morasses, to the height of 600 feet: on this slope are the geyser-jets. The first springs reached are in a marsh of mud and moss, and lie on the south-west corner of the district. "The Great Geyser," Mr. Gould continues, "is furthest east of all the springs; it is indicated by a mound of sintery deposit, like a heap of dry grey leaves, piled up about 30 feet above the soil." At the summit of the mound is the basin, generally full to overflowing. According to Mr. Gould, it measures 56 feet by 46 feet, and is 4 feet deep, shelving gently to the bore, which is 9 feet 6 inches across, and 76 feet deep. After patiently waiting a couple of days, Mr. Gould saw a magnificent eruption of Great Geyser, heralded by violent concussions of the ground, and a loud rumbling noise, which made the ground tremble to a considerable distance around. This sound, no doubt, is due to incipient attempts at an explosion, followed by the sudden condensation of the steam within the tube. By leading steam from a small lecture-table boiler to the bottom of a vessel containing water, these rattling sounds may be well imitated, together with a shaking of the whole apparatus following each detonation.

In fact, there is no reason why artificial geysers might not be perfectly well set up, on a somewhat large scale, in places of popular resort. There is one beautiful feature, however, in the geyser which cannot be artificially imitated—at any rate, within reasonable limits of time—and that is the formation of the tube and basin of the geyser. To this let us now turn.

The water that is ejected from the geyser is

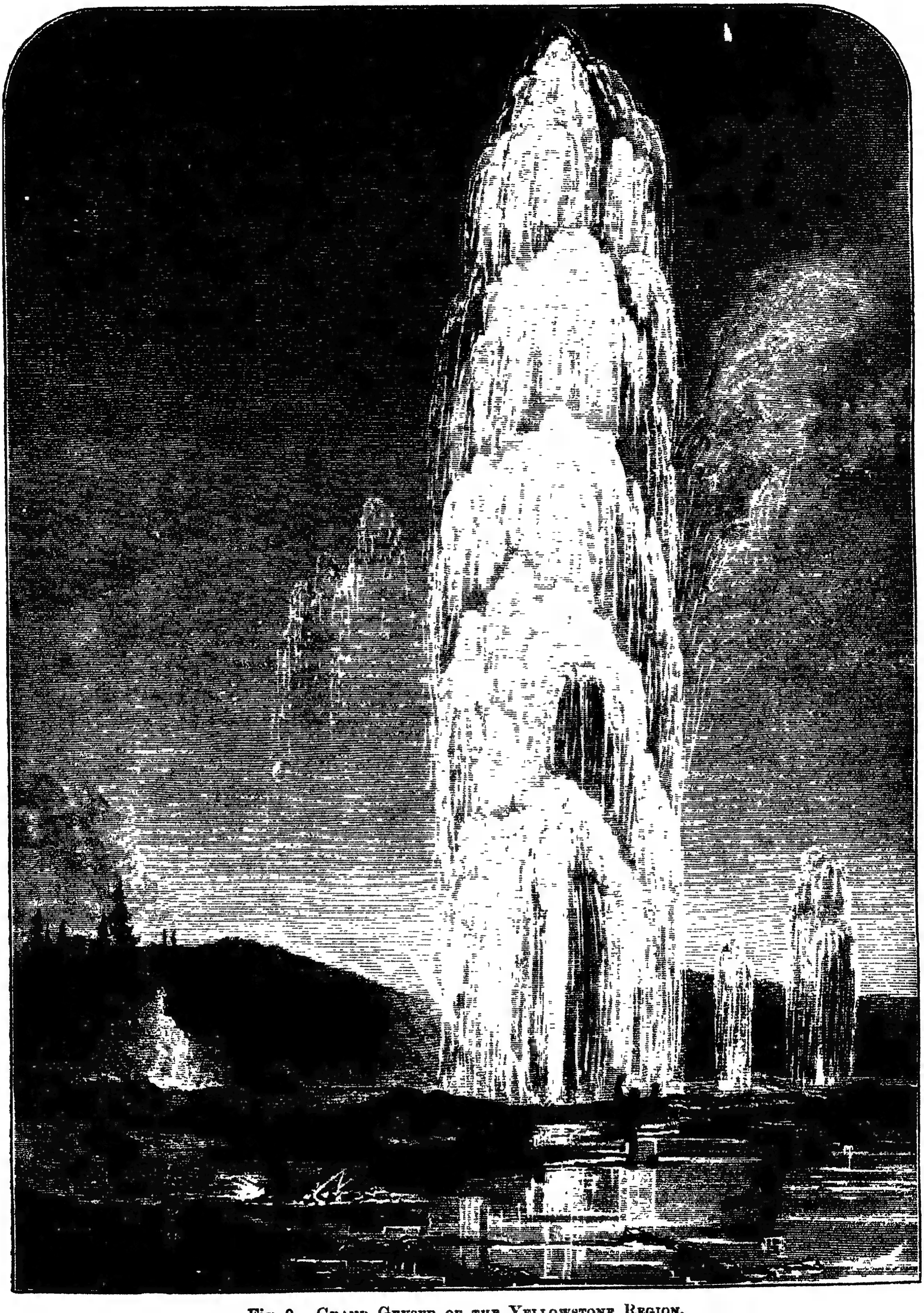


Fig. 9.—Grand Geyser of the Yellowstone Region.

impregnated with silica or flint, a substance which every one knows is a most insoluble body. At a high temperature, however, water is able to dissolve silica to some slight extent. Mr. Faraday, moreover, ascertained that the solution of silica is promoted by the presence of soda; and this alkali is contained in the volcanic rocks in the neighbourhood of the geyser. When the hot siliceous water is cooled by exposure to the air, the silica is deposited, being no longer able to remain in solution, not only on account of the cooling of the water, but also because a decomposition of the compound of silica and soda takes place, owing to evaporation and the action of the carbonic acid in the air. The silica is thus deposited as a solid crust, which hardens into a rock, called *siliceous sinter.* Vast quantities of this sinter are deposited by the hot siliceous springs in St. Michael's, an island of the Azores. Objects placed in these springs become rapidly petrified by the incrustation of the silica, just as in our Derbyshire caves birds'-nests and other things are petrified by the calcareous water, which deposits successive layers of lime. In the geyser-basins, leaves of the birch-tree and various coarse grasses are found in this petrified state; and very beautiful some of these petrifactions are, for the precious opal is chemically the same substance as this sinter; and, indeed, the smooth basin of the geyser is lined with a variety of opal, denser and more translucent than the sinter round the edge.

These facts render it easy to understand how a bubbling thermal spring can and does raise up a boundary-wall around itself. Then, as the water flows over the embankment it has made, the walls will grow higher and thicker, until at last a basin, and ultimately even a tube, may thus be formed. Experiment has shown that in twenty-four hours a film of silica as thick as a sheet of thin writing-paper is deposited. At this rate, 1,036 years would rear the tube of the Great Geyser. The overflow of the silica-laden water would, of course, gradually form an embankment surrounding the inner tube, and in the lapse of time the *débris* and aqueous deposits from the surrounding hills would tend to diminish the apparent altitude of the hollow cone. Thus we should have much the appearance that is now presented in the geyser districts of Iceland. An interesting confirmation of this theory of geyser growth is derived from history. In the earliest trustworthy records of Iceland, which date back 1,000 years, there is no mention of these fountains of boiling water; and hence, as so striking an object would be sure to have arrested attention, we may reasonably conclude that the geysers were not then in operation. The first notice of the Great Geyser occurs nearly seven centuries ago, when, if the observed rate of siliceous deposit is to be depended upon, its tube must have been about 25 feet deep. Two hundred and fifty years ago, we find it recorded as regularly erupting every twenty-four hours. But as the tube grows higher and the column of water within deeper, and the pressure below greater, a more exalted temperature is necessary to reach the boiling-point, and hence longer and more uncertain periods should intervene between each eruption. This is, indeed, precisely what has occurred. At length, if the process of accretion be continued, we should expect to find an eruption at rare intervals; and ultimately the great depth of the column of water would create so enormous a pressure that the temperature of the boiling-point could never be reached by the source of heat below, and the geyser would then cease to erupt at all. This suicidal ending of a geyser's life actually takes place, for, in the neighbourhood of the active geysers, there are to be seen mounds containing pools of water or "laugs" of great depth, which are doubtless extinct geysers.

In fact, an interesting experiment made by Mr. Baring-Gould, which has not received the attention it deserves from its important bearing on this point, experimentally showed the possibility of killing a geyser by suddenly increasing the depth of water in its tube. "We," Mr. Gould writes, "raised the depth of the well south of the blue ponds 20 feet, by turning the stream from these ponds into it, and completely altered its character, converting it from a well of furiously boiling water to a pool steaming tranquilly. Not satisfied with this experiment, we tried another, and dug into a small puddle of hot mud. It was at once converted into a bubbling pool of five jets."* This, of course, is the converse experiment—namely, relieving the superincumbent pressure to some extent

Nowhere are the stages in the growth of a geyser seen on a grander or more perfect scale than in that wonderful region of the United States known as the Yellowstone. This tract, which has been explored in comparatively recent times, lies in the heart of the Rocky Mountains, at the north-west corner of the territory of Wyoming, in the vicinity of lat. 44° N., and long. 110° W. Within the last few years, a careful survey of the Yellowstone has been made by American geologists. Attention was first drawn to this remarkable region by the report

* "Iceland: its Scenes and Sagas," p. 361.

of an exploring party who surveyed the district in 1870: following the Madison River, one of the tributaries of the Missouri, they discovered, on its west bank, a valley, literally swarming with geysers and steam-jets, which, in volume, number, and height of eruption, far exceeded the Icelandic display. The most prominent geysers were within an area two miles in length and one in width, and they received the names of the Old Faithful, the Castle, the Grotto, the Giant, the Giantess, the Fantail, and the Beehive geyser. The following description is given by the artist attached to the survey-party:—

"The most remarkable of all the boiling springs, was the beautiful geyser that was appropriately named the 'Giantess.' The ground sloped gently to the mouth of the crater, which did not protrude above the surface, as was the case with the other geysers in active operation. When quiet, it was a clear, beautiful pool, caught in a silica urn with a hollow, bottomless stem, through which the steam came bubbling like the effervescence of champagne from the bottom of a long, hollow-necked glass; the mouth of the vase, represented by the surface, was 20 feet by 30, and the neck, 50 feet below, was 15 feet by 10. All at once, it seemed seized with a terrible spasm, and rose with incredible rapidity, hardly affording us time to flee to a safe distance, when it burst from the orifice with terrific momentum, rising in a column the full size of this immense aperture to the height of 60 feet; and through, and out of, the apex of this aqueous mass, five or six lesser jets were projected to the marvellous height of 250 feet. These lesser jets, so much higher than the main column, and shooting through it, doubtless proceed from auxiliary pipes leading into the principal orifice near the bottom, where the explosive force is greater. This grand eruption continued for twenty minutes, and was the most magnificent sight we had yet beheld. All we had previously witnessed seemed tame in comparison with the perfect grandeur and beauty of this display."

Many other extraordinary natural features occur in this wonderful district of the Yellowstone, besides geysers, and it is surprising that so unique a corner of the earth should only lately have become known. After the publication of Mr. Langford's account, from which the foregoing extract is taken, Dr. Hayden, Director of the United States Geological Survey of the Territories, organised a scientific exploring party, and made a careful and systematic survey of the entire district. Numerous photographs of the geysers were taken by Dr. Hayden, which confirm the earlier descriptions; in fact, Dr. Hayden states that in the eruption of the principal geyser he observed "a column of water, apparently 6 feet in diameter, to rise to the height of 200 feet, while the steam ascended a thousand feet or more. So steadily and uniformly did the force act that the column of water appeared to be held there for some minutes, returning into the basin in millions of prismatic drops. This was continued for about fifteen minutes, and the rumbling and confusion attending it could only be compared to that of a charge in battle. It would be difficult to describe the intense excitement attending such a display."* (Figs. 9, 10, 11.)

The last inquiry that suggests itself relates to the source of heat which is the *primum mobile* of geyser activity. That a high temperature exists beneath the surface of the ground is proved by the gradual increment of temperature which is noticed in deep mines or wells; whilst the phenomena of volcanic eruptions would seem to indicate a molten interior beneath the solid crust of the earth. In fact, the periodic eruptions of some volcanoes, such as Stromboli, very much resemble the action of the geysers. Some have supposed, and with good grounds, that the infiltration of water through minute fissures in the bed of the sea or in the land, may be the source of volcanic disturbance. It is this infiltration which feeds the geyser-tube with water, but here only a mere surface drainage is necessary. If, however, the water can slowly penetrate through successive strata until it reaches the assumed molten interior, steam would be generated and be unable to escape through the capillary passages, charged as they would be with water. The enormous elastic force of the confined steam thus produced is, according to this theory, the cause of volcanic activity, and in support of this it is observed that bubbles of steam are constantly found entangled in the erupted lava, and, moreover, vast clouds of steam accompany every volcanic discharge. But in the case of geyser activity, we have seen that we need merely a sufficiently powerful source of heat applied to the water in the tube, and the steam there generated will do the rest. Now, this heat may reach the geyser-tube through certain heat-bearing rocks which may play the part of heat-conductors from below, or there may be local causes

* Various descriptions of the Yellowstone Region have been published. The best of them is, of course, Dr. Hayden's; but Lord Dunraven's "Great Divide," "The Countries of the World" (vol. ii.), and a little work published anonymously under the title of "The Wonders of the Yellowstone Region," also give full accounts.

which generate a sufficient supply of heat in the proximity of the geysers, without reference to any hypothetical central furnace. In geyser regions, which are also volcanic regions, extensive beds of

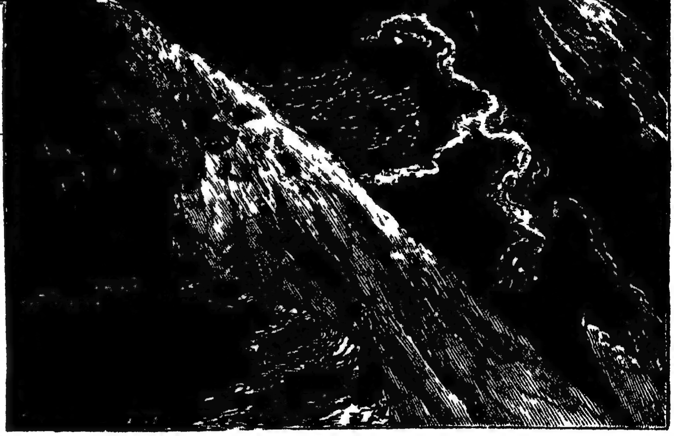



Fig. 10.—Mammoth Hot Springs of Gardiner's River, Yellowstone Region.

sulphur and of pyrites are to be found. Decomposition of the latter is readily produced by the agency of water and air, and in the process of decomposition great quantities of heat are evolved. It was suggested by the late Sir Henry Holland, that this might be the source of heat in the geyser. So long ago as 1810, this distinguished traveller and physician, after a visit to the Icelandic geysers, wrote that "the source of the heat which can generate permanently so enormous a quantity of steam, must, doubtless, reside below the rock. It certainly seems most probable that the appearances depend upon the action of water upon vast beds of pyrites. The heat produced by this action is sufficient to raise an additional quantity of water in the form of steam, which makes its way to the surface, and is there emitted through the different clefts in the rocks."

This suggestive observation has recently been confirmed by other scientific men. If we compare the surroundings of the geysers of Iceland with the character of the soil in the geyser district of North America, the probability of chemical action giving rise to this internal heat is much strengthened. Mr. C. W. Vincent in this connection remarks* that "the whole of the Yellowstone district (in North America) is covered with rocks of volcanic origin, of comparatively modern date. Boiling

* Burton: In a paper read before the Society of Arts (Jan., 1873). See "Ultima Thule; or, a Summer in Iceland."

springs, mud-caldrons, and geysers are found in all parts of the region, and the description given of the Yellowstone Lake and its vicinity in every respect coincides with those of the geysers, mud-caldrons, and hot-springs of Iceland.

"In all cases there was found to be free access of water; free sulphur was widely dispersed, and the steam-jets were invariably accompanied by large quantities of sulphuretted hydrogen. The subterranean action in that country seems to have been of sufficiently long standing to build up geyser-tubes of so great a length, that the internal pressure has found other vents, rather than lift the enormous column of water above it."

And now we must bring this lengthy talk on geysers to a close. We have endeavoured to trace the history, and understand the philosophy, of one of the most interesting and curious of natural phenomena. We have seen how, in all probability, the geyser grows, bursts forth into active life, and then comes to an inglorious close. Its life-history, in fact, is well sketched by Captain Forbes, in the words with which we shall finish this paper:—"The geyser in infancy is the bubbling thermal spring; matured in years, the roistering geyser; old age creeping on the tranquil 'laug,' light wreaths of vapour crawl over the still simmering contents of its fiery azure grottos, where it calmly awaits the fleeting of its once restless spirit, which is finally diverted amid the thunders of natural convulsions, leaving its sepulchral mound and ruined shaft as mementoes of its former vigorous existence"

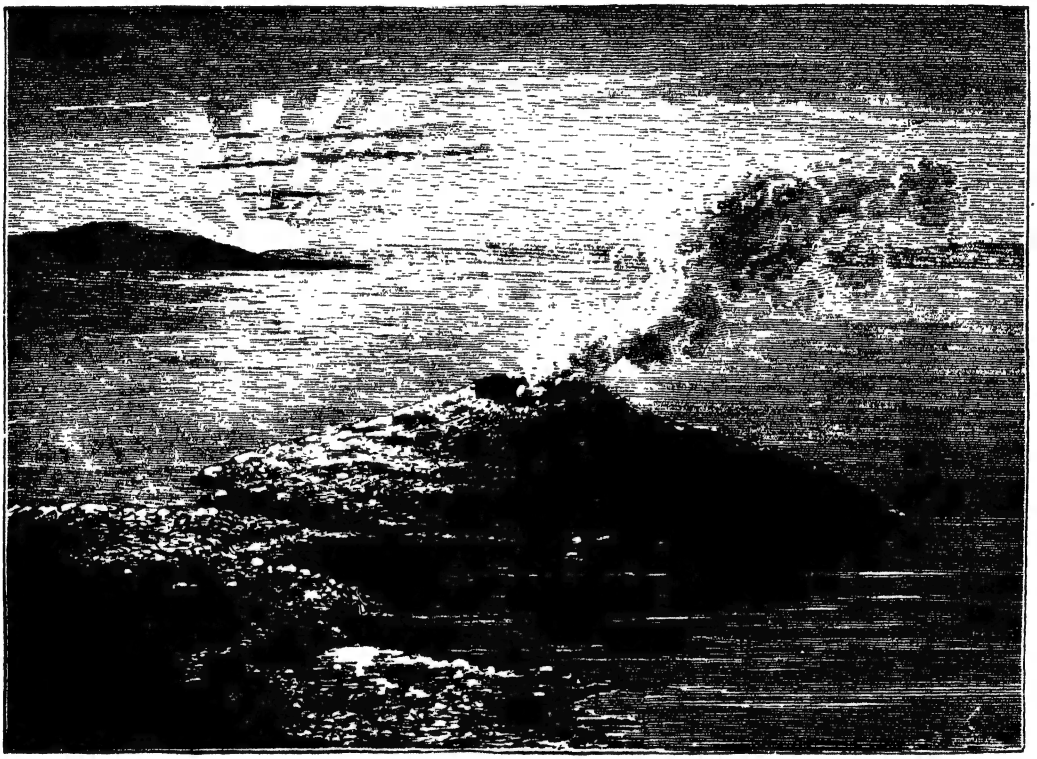


Fig. 11.—Hot Spring of Yellowstone Lake.

# DOUBLE STARS.

By T. E. Espin, B.A., F.R.A.S.

When we look up at the stars, we are apt to think how still and peaceful they are: they appear quite stationary. And yet the astronomer knows that each one is moving—some with incredible speed, invisibly to the unassisted eye, yet visibly in part in the instruments at his disposal. He would tell us that those groups of stars—the Great Bear, and Orion's starry belt, and many others we are familiar with—were all changing their form: a change visible to the naked eye only after innumerable years. There are no fixed stars. If we have a telescope at our disposal, and turn it on different parts of the heavens, we shall soon come across stars that appear single to the naked eye, but are resolved into two with very small optical power. And very often we see these two stars of the same size, and they seem to form a perfect pair; and not only in size, but we find their colours to be remarkably matched, so as to be complementary. Thus one star will be orange, and its companion blue; and, more rarely, a red star with a green companion. And we immediately remember that the combined light of the two stars would be white in either case, for we know that white light is composed of the three colours called primary colours, red, yellow, and blue. Seeing, then, this peculiarity, we are next led to inquire whether there may not be some connection between these two stars, since they fit so well together. Astronomers will tell us that there is a connection between some—a most interesting one, for they find that many of these pairs have peculiar motions of their own, depending on each other's attraction. They indeed revolve round their common centre of gravity. A great many double stars (over 10,000) are now known; but not all of them are so connected, for one star may be a great distance behind the other, as we often notice two objects appear side by side, though one is in reality very much more distant than the other. Sir William Herschel was the first to discover that certain stars, whose places he had determined, after a few years had manifestly changed their positions with respect to each other. In twenty-five years he found nearly fifty that had so changed; and now between 600 and 700 are known. Thus a new field opened to astronomers, extending our wonders in the sidereal world, and calling up fresh thoughts on the fixed stars. Let us look at the periods of some of these *binary* stars, as they are called. Zeta ($\zeta$), in the constellation of Hercules, has a very short period—only about thirty-six years; next comes a star in the Northern Crown, Eta ($\eta$) by name, whose period is about forty-three years. These are comparatively short periods; but some have periods of thousands of years. The bright star Castor, in the constellation of the Gemini, has a period of 600 years. But not only do we find two stars connected as in Gemini, but in some cases three, and more. And they vary, too, in size very greatly, and are not, as we first supposed, only of the same magnitude. Sometimes there is a star with a very tiny companion—so tiny that only large instruments will show it; and it has been thought that there are cases where these little companions shine by reflected light, just as the planets reflect the sun's light, but with this difference—that whereas all our planets are quite small compared with the vast size of the star round which they revolve, and which we call the sun, the companions of these stars must be of vast size. The star known as the Dog-star—namely, Sirius—has a tiny companion so very close that it is only with large telescopes that it can be seen. While mentioning big stars with companions, we must not forget the beautiful companion to the star Antares, in the constellation of Scorpio. Here we have a most fiery-red star with a tiny green companion. This colour is not the effect of contrast, as it may be in some cases, for when the moon passed over Antares, Dawes saw the companion after the moon's limb had hidden the bright star, and it was as green as ever.

Returning to our subject, we find that these connected systems consist for the most part of two or more stars of the same or different magnitudes revolving round their common centre of gravity, and that some of the stars with companions may be the illuminators of their little attendants. Before we proceed to speak of some very curious thoughts that arise from the existence of these binary systems, we may well for a minute consider one of them: one whose movements have been so swift as to be easily visible from month to month. This star is situated in the constellation of Virgo, and is called Gamma ($\gamma$). Herschel, from casual observations of older date, was able to attack the problem of a

solution to the orbit of this wonderful binary star. In speaking of his results, he says :—"If they be correct, the latter end of the year 1833, or the beginning of 1834, will witness one of the most striking phenomena which sidereal astronomy has yet afforded—viz., the perihelion passage of one star round another with immense angular velocity [here he states the angular velocity]. As the two stars will then, however, be within little more than half a second of each other, and as they are both large and nearly equal, none but the very finest telescopes will have any chance of showing this magnificent phenomenon. The prospect, however, of witnessing a visible and measurable change in an object so remote, in a time so short, may reasonably be expected to call into action the most powerful instrumental means which can be brought to bear on it."

The passing of one star round the other occurred, however, somewhat later—in 1836, when the stars were perfectly inseparable to ordinary telescopes. In the great telescope of Struve, at Dorpat, they were still visible as a not perfectly round star. Since then, they have expanded more and more, till now they may be seen with slight optical means. Thus, then, at a distance inconceivable, wonderful changes have been going on—changes which our minds fail to take in. Could we write them down, figures would pile on figures till all sense of distance was lost. Miles are useless for measuring: astronomers use something that travels at the rate of 184,000 miles a second—namely, light. Even then we could not half understand the immense distance of Gamma in the constellation Virgo. Many, many years must light travel to reach our little world from those two suns. They might even have been extinguished hundreds of years ago, and yet we should still see them—so vast are the distances of some stars. When we read in 1877 of the new star that suddenly shone forth in the Swan, we perhaps forgot that whatever caused it to blaze out as it did was not in operation then, but that the combustion occurred hundreds of years ago.

We have already seen how strangely the colours blend in many stars; but there is a strong suspicion that the colours in some binary stars alter as they complete their revolution—nay, even that the stars themselves change in brightness.

Wonder thus piles on wonder: first, we find two stars, which we believed to be fixed, in rapid motion; next, we find that they change in colour; and finally, that their apparent brightness is also variable.

We know that this our little earth turns round a central body called the sun; we know that there are eight other large bodies, which we call planets, also revolving in orbits round the sun; and we have already called our sun a star, and we may well believe that all the stars we see are suns. Some, we are sure, differ greatly from our own both in size and in structure, but yet they are suns; and therefore it is a natural inference to say that these suns have planets which rotate round them, as those in our solar system rotate round our sun. And we have seen that perhaps one or two of these planets have actually been observed as companions to big stars; and though those companions must be vast—perhaps as large as our sun, if not larger—and the controlling body proportionally large, we may look upon all other planetary systems as resembling our own; and just as we may increase each side of an equation by the same quantity without affecting the relation between each side, so we may add vast masses to those distant suns, but yet retain the same fundamental basis. Thus we may argue when we think of single stars; but what shall we say when we come to such stars as Gamma in the constellation Virgo? What combinations and wonders must arise there! Let us in thought transplant ourselves to a planet attendant on one of those suns. We have now two suns instead of one—two suns which we may well believe to be very vast compared with ours. Let us suppose the case of a planet which revolves round one of them. At one time at noon, two suns pour down their light side by side on the planet; rather more than a quarter of the planet's year elapses, and then one is setting when the other is only just reaching its highest point in the heavens, and *vice versâ.* In fact, no sooner will the west have lost the glow of the one setting, than the east will be tinged with the other rising. Another quarter of a year elapses, and then there is no more night, for as one rises the other sets; and a quarter of a year later we have a repetition of the short night; and then, after another quarter, regain the position started from. But here we have supposed the suns to lie in the same plane. But what new complications will arise when they do not—when they are themselves moving at one time with prodigious velocity, at another very slowly? add to this the planet's own inclination to its orbit. Then, again, what if we take into consideration the changes that the planet must undergo from the varying light of these suns?

Suppose we take the case of a planet attendant

on one of the trinary stars. Then we have possibly an orange and two blue suns. What wonders we should see in our imaginary planet, besides those in the sky! At one time, all three suns will pour their light upon the planet, and then the light will be white, just as it is on our earth. But suppose that at another part of the planet's revolution it comes between the orange and the two blue suns, then one-half of its day will be bathed in blue light. To imagine the effects, let us take a piece of blue glass, and look through it at the landscape, and we shall have some idea of the wonders that would appear. But just as these two blue suns are setting, the orange one will be rising, and all the marvels of light and shadow will come out in striking contrasts and modulations of shade into shade. One side of a tree will reflect the blue light, the other side orange. Those who have seen the light of our setting sun upon the snow capped mountains of Switzerland will know how wonderful the tints are; but what would they be on the planet we are imagining? Perhaps this planet has moons: there, again, what strange appearances there will be in the sky at night! Sometimes these moons will appear perfectly white, when the three suns all illuminate them equally; at another time, half blue and half orange; and again, all blue, with just a crescent of orange; or all orange with a crescent of blue. Imagine what wonderful appearances the inhabitants of a planet with eight moons like Saturn would have. In the nearer, they would see the colours altering from hour to hour. So far, then, we have been speaking of the beauties of such a planet; but just as it is improbable that on any of our planets beings constituted as ourselves could live, so we may say that we could not live on one of these imaginary planets. No planet revolving in an orbit at any considerable distance from one of these suns, could accomplish a revolution without getting very much perturbed by the other two. Its inclination would be constantly changing; its seasons would never be the same year by year; and lastly, every revolution it would be imperilled by the attracting influence of the other two suns. Very likely it would have scarcely performed a revolution round one sun, before it would be dragged off, with the elements of its orbit entirely changed, to circle round another; and so on through infinity, till one sun obtained the mastery, and ever bound the planet to itself.

Such are some of the speculations that arise from double stars—speculations which cannot fail to be indulged in by all who think on this subject, so full of fascination and interest. Each observer may draw for himself other wonderful pictures from the double stars, and get lost amid their grandeur. We have considered cases comparatively simple. Where should we be when we came to multiple stars? What new combinations of colours would arise!

One double star will thus furnish us with thoughts which ought to make *ennui* impossible; and with very moderate means, we may also be able, not only to read of the motions and colours of double stars, but actually ourselves see to them in all their wonder and beauty.

## FLESH-FEEDING PLANTS.

By F. Buchanan White, M.D., F.L.S., Editor of "The Scottish Naturalist."

We have already seen (pp. 96 to 103), that the majority of plants of the higher classes obtain most of the materials on which they feed from the soil, by means of their roots, or, in the case of water-plants (as the Duckweed), which are not anchored to the soil, from the water in which they live. We have also seen that roots cannot absorb solid particles, but that their food is taken in the form of either a liquid or a gas, and, moreover, that, as a rule, roots are not able to reduce, by chemical influence, solid bodies to a liquid or gaseous state, and so utilise them for food. There is, however, a certain limited number of plants which obtain their nutriment in quite a different manner; and as the chief food of these plants consists of insects and other small animals, they have been termed insect-devouring, or flesh-feeding, or, in other words, *carnivorous* plants.

If we go to the nearest peat-bog and search in damp places, we shall be almost certain to find specimens of the pretty little plant known to botanists as the Round-leaved Sundew (*Drosera rotundifolia*). Its leaves, which are reddish in colour, and from an inch to two inches long, grow close to the ground in the form of a rosette, from the centre of which rise, in July and August, the flower-stalks, bearing each

several small white flowers. If we take off a leaf and examine it, we shall find that the blade is roundish, and furnished with a long stalk—in fact, resembling somewhat a flat spoon. The upper surface of the blade is covered with rather stout, erect, hair-like objects, each with a roundish head, which is covered with a sticky fluid. Moreover, we shall observe that these hair-like bodies are longest at the edge of the leaf, and that they gradually diminish in length from the edge to the centre, where they are much shorter, and rather fewer in number. I have called these objects "hair-like," for such is their appearance, but they are not really hairs. Vegetable hairs, as it has been already mentioned (p. 98), are simply little bladders or cells elongated, instead of being globular as in other parts of the plant. But the hair-like things on the Sundew are much more complex in

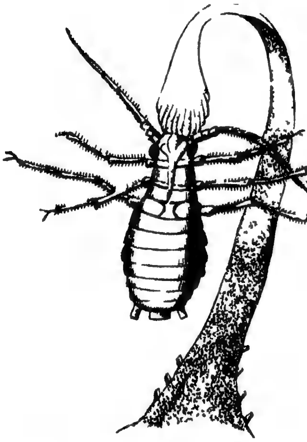


Fig. 1.—An Insect seized by a Tentacle of the Round-leaved Sundew. (*After Edouard Morren.*)

structure, as we shall see if we examine them with a microscope, and are built up of the various structures that enter into the composition of the leaf, of which they are, in reality, prolongations. In fact, they differ as much from true vegetable hairs as one's fingers do from the hair of the head. It will therefore be convenient to use some other name, and we cannot do better than adopt the term "tentacles," which Mr. Darwin has applied to them (Fig. 3).

We have already seen that the roundish heads of the tentacles are covered with a sticky fluid which is very tenacious and viscid, as we can learn by touching it with the end of a pin, and seeing what a long thread can be drawn up, just as might be done with strong mucilage or treacle. It is therefore evident that if any small object, such as an insect or a seed, were to fall upon the sticky stuff, it would be retained, just as a small bird is held by a twig covered with bird-lime, or a fly by the treacle on to which it has foolishly ventured. Now, if we look closely at the leaves of the plants of Sundew that we have found, we shall discover that almost every leaf has got some small object entangled amongst its tentacles—flies, seeds, small leaves, and suchlike things—and, possibly, while we are in the act of looking, we may see a fly alight on a leaf and get its feet entangled, or, perhaps, a seed or a leaf blown thither by the wind. But as it will not be convenient to stay all day in the peat-bog, suppose we dig up some plants and remove them to our own home, where, planted in wet moss, they can be studied at our leisure? As we dig them up, we may notice how small the roots are, and, though containing much moisture, what little nutriment, except for such low plants as mosses (which derive most of their food from the air), the spongy peat affords.

After our plants have become reconciled to their change of residence, we shall try some experiments with them. In the first place, we can take a common house-fly (to avoid needless cruelty, we may as well kill it), place it on the sticky top of one of the outer tentacles, and watch the result, which, in most cases, will be as follows:—

(1st) The tentacle will very soon (often in less than a minute) begin to bend or incline itself towards the centre of the leaf, and will continue to bend until the centre is reached.

(2nd) Soon after the tentacle that has the fly has begun to bend, the neighbouring tentacles will commence to bend towards it, as if they, too, wished for a share of the ]

(3rd) The sticky fluid (which is known as the *secretion* of the tentacles, because it is secreted or formed by their round heads or glands) begins to increase in quantity and envelope the fly, which, if it were still alive, would be speedily killed by the secretion filling up its breathing-holes or spiracles.

(4th) The fly, by the bending of the tentacles, is carried in a sort of rolling motion towards the centre of the leaf, and deposited among the shorter tentacles, the outer and longer tentacles being all incurved upon it and holding it there.

(5th) The edges of the leaf become more or less incurved, so that the blade of the leaf forms a kind of basin, at the bottom of which is the fly, held by the tentacles and copiously bathed in the sticky fluid or secretion.

(6th) After remaining in this position for many hours, or it may be for several days, the tentacles

begin to unbend, and gradually return to their former erect position, the leaf becomes flat again, the secretion is less copious, or even dries up, and if we examine what is left of the fly we shall find that only the hard parts, such as the outer skin, wings, &c., remain, and that all the soft contents of the body have disappeared (Fig. 1).

We may now repeat this experiment, but, instead of taking a fly, we can try little bits of meat,

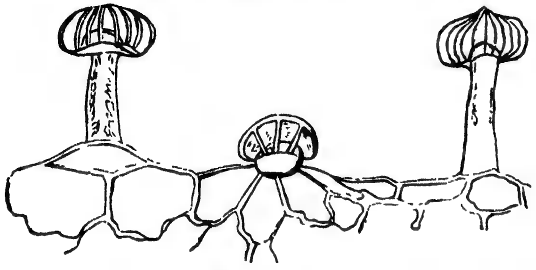


Fig. 2.—Gland-bearing Hairs on the Leaf of a Butterwort. (*After Edouard Morren.*)

cheese, bone, white of egg, small seeds, or, in fact, anything that can be called "eatable," and we shall find that all of these affect the plant in the same way that the fly did, but in a more or less different degree, according to the substance used; the meat and other animal food having the strongest and most rapid effect.

In the next experiment we can use things not good for food, such as little bits of hair, thread, stone, cinders, glass, and similar things. Under the influence of these, the tentacles bend, but not with such rapidity; the secretion will not be so greatly increased; and instead of the object being retained for many hours, or even days, the tentacles will begin to unbend after a short time, and release it. In the case of the latter (the "uneatable") class of objects, we shall find that the matter experimented with has been quite unaffected and unaltered by its contact with the tentacles, while in the case of the other class all that is "eatable" or soluble will be found to have disappeared or melted away, only the hard, innutritious parts, if there are any, being left.

A third experiment may be made by taking a needle and touching the round head or gland of a tentacle with the point. If we touch it once or twice only, no effect is produced, but if we go on touching it several times rapidly in succession, or keep a continued pressure on it, the tentacle will begin to bend, the bending taking place on this, as well as on most other occasions, at the lower part of the stalk of the tentacle. From this we may learn that one or two accidental touches, such as might be given by the leaf of a neighbouring plant being brushed against the tentacles by the wind, will not excite action which would be useless; we can also prove by experiment that falling water—such as rain—has no power to make the tentacles move.

For the next experiment we must provide ourselves with some litmus paper, which can be procured at any chemist's shop. Litmus paper is used for ascertaining whether a liquid is acid or not. If it is acid, the paper turns red when dipped in the liquid, which we may see for ourselves by wetting a piece with vinegar, or any other known acid fluid. Now, take a bit of unused paper, and touch the secretion of a leaf that has *not* been excited to action by putting an object on its tentacles, and it will be found that no change of colour takes place. Give the same leaf a small bit of meat, wait till the secretion begins to flow in increased quantity, apply the litmus paper to it, and it will be seen at once, by the change of colour, that the fluid, which was not acid before, has now become acid.

But, before going further, we had better consider what we have learnt from our experiments, which may be summed up as follows:—

(1) The tentacles of the leaves of the Sundew are capable of catching and retaining flies or other small objects which have come in contact with the sticky secretion of their glands.

(2) The tentacles and the edge of the leaf have a certain power of motion, which tends to convey an object, caught by an outer tentacle, towards the centre of the leaf.

(3) This motion is excited by the head or gland of the tentacle being repeatedly or continuously touched.

(4) The tentacles remain bent over an object so secured for a greater or less period of time.

(5) "Eatable" (or organic) matters, and especially soluble animal matter, have, as a rule, much greater influence than "uneatable" (or inorganic) matters, whose effect is much less. The tentacles also retain in their embrace the former objects much longer than the latter.

(6) In addition to the movement of the tentacles, an increased quantity of the secretion is poured out from the glands, especially when the object exciting the movement is of an "eatable" nature.

(7) The result to an object of the "eatable" class of being clasped by the tentacles and bathed in the secretion, is that all the nutritious part of it is dissolved and disappears. An "uneatable" object is unaffected.

(8) The secretion of a leaf not excited to action

is not acid, but it becomes acid after action has been excited.

We have thus still to learn what has caused the dissolving of the bits of meat or other animal matter that has disappeared in the embrace of the tentacles—what has become of it, and what good it does to the plant. As it is within the power of every one to prove for himself by experiment the influence for good upon the plant of a supply of nutritious, and especially animal, matter, we may consider this first.

If we take a number of Sundew-plants, and divide them into three lots, giving each lot similar advantages for growing, but covering one with fine gauze, so that no flies can be caught by the leaves, leaving the second uncovered, but giving it no special food, and regularly feeding the third lot with pieces of meat or other suitable food, the more advanced and luxuriant growth of the fed lot over the other two, as well as the superiority of the uncovered plants to those covered and prevented from catching flies, will clearly demonstrate that a supply of animal food is not only advantageous, but almost necessary.

Moreover, it proves that the animal matter which has disappeared in the embrace of the tentacles has gone to feed the plant, having been sucked up or absorbed by the leaf.

But how has it been dissolved? We saw in a former article that plants, as a rule, can take in food only in the form of a liquid or a gas, and that they have very little power to dissolve solids, and so utilise them for food in the way that animals do. The power, therefore, of dissolving solids, such as bits of meat, is by no means usual in plants, and we must try to find out how the Sundew manages to do it.

We have seen that the objects which the Sundew can act upon are precisely the things which an animal could use for food; and that those matters—such as hair, stones, the hard skin of insects, &c.—which the animal cannot use, are just those which the Sundew also rejects. When an animal has put food into its stomach, the food is acted on chemically, or what is called digested, by the gastric juice, which consists of a ferment—called pepsin—and an acid, neither of which alone by itself has the power of digestion. But we have proved, by our experiment with litmus paper, that the secretion of the tentacles of the Sundew contains an acid when it is acting; and if we compare the action of animal gastric juice on bits of meat with the action of the secretion of the Sundew, it seems clear that some ferment—similar to, if not identical with, the animal ferment pepsin—must be present in the Sundew secretion. It has, moreover, been found that the secretion of the Sundew gives out under certain circumstances a strong smell of pepsin. But the reader who desires to learn more about this will do well to consult Mr. Darwin's "Insectivorous Plants," or some of the other works that have been written on the subject.

We noticed as we dug up the Sundew-plants how small the roots are, and how poor the moist soil in which they grow. The use of the roots seems to be merely, in addition to anchoring the plant in the soil, to suck up water (of which the leaves with their copious secretion require a great deal), and not, as in most plants, to provide food.

Besides the Round-leaved Sundew, two other kinds grow in Great Britain, and about a hundred elsewhere, and all seem, without exception, to have the same insect-catching habits as the one we have been studying, and to be, like it, dependent upon animal food. There are also some other plants of the same family which are of a like nature, though the mechanism by which they secure their insect food is rather different; but as there is another common British plant which is carnivorous, we will consider it, before proceeding to describe another very interesting member of the Sundew family.

The common British plant alluded to is the Butterwort or Cuckoo Shoe (*Pinguicula vulgaris*), which, like the Sundew, grows in damp, peaty places in many parts of the country, though it is rather rare in the south. The Butterwort has a rosette of eight or nine broad, pale-green leaves, lying flat and pressed to the ground. The purplish flowers appear in summer, and are borne singly upon longish stalks. If we take off a leaf and examine it more closely, we shall see that it is oblong in shape, with a very short stalk, the tip blunt, and shaped like the prow of a boat, and the margin of the leaf curled in for a short distance. The texture of the leaf is rather thick, succulent, and greasy to the touch; and its upper surface is closely studded with small, shortly-stalked glands, and others with rather longer, but still short, stalks (Fig. 2). From these glands a colourless fluid (so sticky or viscid that it can be drawn out into long threads) is secreted or poured out.

As we are looking at the plants, we cannot well avoid noticing that almost every leaf has a greater or less number of small insects, seeds, bits of leaves, &c., adhering to its sticky surface, and, remembering what we found on the leaves of the Sundew, we

may perhaps begin to suspect that these have not been caught in this manner without a purpose.

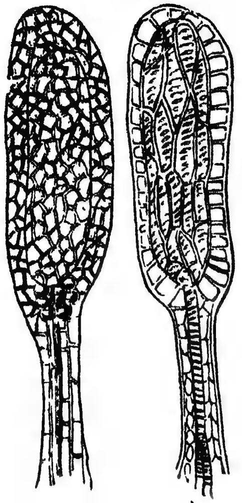


Fig. 3.—Structure of a Tentacle of the Sundew: (a) externally, (b) internally (After E. Morren.) × 20.

But as it is a very great mistake to jump hastily to a conclusion and take anything for granted, we had better dig up some plants and take them home. In doing so we may notice the smallness of the roots, bringing to our memory the small roots of the Sundew, and, like them, apparently more suited for holding the plant in position, and providing it with water from the damp soil, than for feeding purposes.

We can now repeat some of the experiments we made with the Sundew. Select a plant with healthy and clean leaves, and place a row of flies or small bits of meat parallel to the curled up or incurved margin, and between it and the middle of the leaf. After a variable length of time, but usually some hours, the margin of the leaf will gradually curl over still more, and if the objects are not too big or too far off, it will in course of time cover them. If they are too big to be covered, they will be pushed before the advancing margin. The liquid secretion of the glands will also be poured out more abundantly—so copiously, indeed, sometimes, that if it were not for the raised rim formed by the curled-in edges of the leaf, it would run off and be lost, and perhaps carry the flies or other objects away with it.

This experiment can be repeated with matters both "eatable" and "uneatable," as we did in the case of the Sundew. It will then be found that almost all of them will induce the edge of the leaf that is nearest to them to curl in, but that bits of glass and suchlike "uneatable" objects will not excite an increased flow of the secretion, though some fluids will. After the margin of the leaf has remained curved over for some time, it returns to its former position; and it does this sooner when the objects which induced it to curl are not "eatable." We may also notice that the stalked glands have no power of motion such as the glands of the Sundew have, but that it is only the edge of the leaf which can move.

In the next experiment we can test the acidity of the secretion with litmus paper, trying first the secretion *before* it has been made to flow under the influence of a bit of meat, and then after the flow has been excited. The result will be similar to what we found in the Sundew. The secretion in its usual and unexcited state is not acid, but when it has begun to flow, under the influence of the meat, it becomes acid, and changes the colour of the paper to red. Some things, as sugar and starch (which do not, like meat, &c., contain soluble nitrogenous matter), induce an increased flow of the secretion, but do not change its quality, as we may see by dipping the litmus paper in it, and finding that no change of colour takes place.

We may now examine the flies and bits of meat that have been submitted to the action of the leaf, and we shall find that all except the hard parts have been dissolved and absorbed by the plant. Where the dissolved matter is gone, we may see by examining under a microscope the glands of the leaf that has been fed, and comparing them with the glands of an unfed leaf, or portion of a leaf. In the latter the glands are pale green, in the former they are brown, from the organic matter that they have absorbed.

For another experiment we can compare the action of animal gastric juice, and the action of the secretion of the Butterwort. Take a few drops of milk, and add some rennet (which is the preserved gastric juice of a calf) to it; drop also a little upon the leaf of the Butterwort. In both cases the milk will be curdled. This property of the Butterwort (of being able to curdle milk) has been long known, and is said to be still put to practical use in Lapland.

From these experiments the conclusion must be drawn that the Butterwort, like the Sundew, is a true carnivorous plant, which not only catches its insect food, but digests it much in the same way as an animal does. It does not, however, entirely confine itself to animal food, but digests and derives some nutriment from some of the small leaves and seeds which are caught by the sticky secretion. The Sundew also does the same.

The next example of a carnivorous plant that we will take is the one known as Venus' Fly-Trap (*Dionæa muscipula*), Fig. 6, p. 179, which is a member of the Sundew family. It is a native of North Carolina, and, like the Sundew and Butterwort, grows in damp places and has small roots. In cultivation it will grow very well in damp moss. The leaf has two lobes, placed at a little less than


Fig 4 —A Group of Flesh-feeding Plants

1. *Nepenthes*, 2. *Dionæa*; 3 *Utricularia*, 4. *Drosera*, 5, *Darlingtonia*. 6. *Sarracenia*

a right angle to each other. The margin of the leaf is prolonged into a row of long, sharp spikes, and about the centre of each lobe are three small teeth-like hairs or (as Mr. Darwin calls them) filaments. The colour of the leaf is green, but its upper surface, except near the edge, is covered with minute stalked glands (which may be seen with a magnifying-glass), of a reddish colour. The stalk of the leaf, which is flat and wide, is not furnished with these glands.

If we take a fine needle or a bristle and lightly touch one of the filaments, the two lobes of the leaf will come rapidly together, and remain so closely applied to each other that it is difficult to separate them without tearing their substance; and even if we do succeed in forcing them apart, they will close again when released. They will, however, reopen of themselves in the course of a day or so.

If any part of the leaf, except the filaments, is touched, no movement takes place, nor does blowing on the filaments, or dropping water on them, have any effect; from which we may learn that neither wind nor falling rain has any power of inducing the leaf to close.

If a piece of meat or a crushed fly is laid on the leaf (care being taken to avoid touching the filaments), no immediate result will follow. Presently, however, the glands touched by the object, which were quite dry before, begin to pour out a colourless acid (as may be seen by testing it with litmus paper) fluid, and the lobes of the leaf gradually close. At first only the glands on which the meat or fly is lying secrete the fluid, but as the secretion flows over the other glands—which the closing of the lobes will cause it to do by capillary attraction—many of these become affected, and begin to secrete, as may be seen by forcing the lobes sufficiently apart to see what is going on.

This experiment may be repeated with a variety of substances, and we shall find that it is only those which are "eatable" (or that contain soluble nitrogenous matter, such as meat), and which are moreover slightly damp, that cause the secretion to flow and the lobes to close. Substances not containing soluble nitrogenous matter (for example, bits of glass, wood, stone, &c.), or which, if they do, are dry, have no effect.

After a leaf has closed on a bit of damp meat or on an insect, it does not open again for many—perhaps twenty or thirty—days, and after it has expanded it will be found to have lost much of its sensibility, and may possibly never recover it for the rest of its life, especially if its meal has been a large one.

If we can persuade a living insect to walk on to a leaf and touch one of the sensitive filaments, we shall see the use of the rapid closing of the blades; unless the animal is very agile, it is caught and crushed between them, and its juices being squeezed out induce the secretion to flow. If, however, the insect is only a small one, it may escape pressure, and as it is consequently not damp, the leaf soon expands again, as no fluid has been secreted. The use of the comb-like edge of the leaf seems also to be for the purpose of permitting small insects to escape by passing between the spines, while a larger one would be retained. As a leaf can usually make but one hearty meal in the course of its existence, it is desirable that this meal should be a large one, therefore there is an advantage to the plant in letting small insects escape.

When a leaf has opened after its meal, the insect or bits of meat which it closed upon, can be looked for, when it will be found that only the hard indigestible parts are left. All the rest has been dissolved and absorbed, unless the object was too big for the leaf to consume, when part of it may have been left undissolved.

It may here be mentioned that at the moment of the lobes of the leaves closing a slight electric shock runs through the plant. But this and many other strange features of plant life do not properly come under the subject of this paper.

Two out of the three carnivorous plants which we have now been studying, capture their living animal food by means of the stickiness or viscidity of certain of their parts; while the third depends upon the rapidity of its movements. All three have the power of moving some of their parts to a greater or less extent, but only one catches its prey by this means, the other two merely using their motive power to dispose of it after it has been caught or partially caught. All three have probably some peculiarity of scent or appearance which serves as an attraction to insects, but what the lure may be is not yet very well ascertained. There are, however, other carnivorous plants which use several means of attracting insects, and, before quitting the subject, it will be well to describe a few of their peculiarities.

*Nepenthes* (Fig. 4) is a genus of the so-called Pitcher-plants, and includes about three dozen tropical, shrubby, climbing plants, whose carnivorous propensities—long suspected—were established a few years ago by Sir J. D. Hooker. The "pitchers" of these plants are trumpet-shaped or pitcher-like vessels of various sizes and forms, attached by a

stalk (which is sometimes very long) to the tip of the leaf. The pitchers vary in length from an inch to upwards of a foot, and are furnished with "lids" which appear to remain always more or less open. The mouth of the pitcher is strengthened by a thickened ring, which in some cases is prolonged as a funnel-shaped tube downwards into the pitcher, and in others is developed into a row of incurved hooks. The mouth, as well as the under side of the lid, are often brightly coloured, and in most species secrete a kind of honey, which, with the lively colours, are intended as lures for insects. Let us, if we can, imagine ourselves for a moment to be an insect attracted by the honey at the mouth of the pitcher. Sipping the honey, we gradually go farther and farther into the mouth of the pitcher, and, allured perhaps by some real or supposed attraction inside, descend past the funnel-shaped tube or the row of incurved hooks, when, to our horror, we find that these prevent our return, and we must descend farther. But our next step is upon a smooth, glassy surface, which offers no foothold, and, slipping over that, we find ourselves plunged into an acid and digestive fluid which fills the bottom of the pitcher, and is secreted by the glands which line the lower part of the inside. Resuming again our character of investigators, we see that the pitchers of *Nepenthes* do not depend upon any motive power nor upon any stickiness to catch their victims, but that they first allure their prey by a brightly-coloured and honeyed bait, then facilitate its descent into the pitcher by a tube or row of incurved hooks which permit of easy entrance but prevent egress; that the descent of the insect is next secured by a glassy surface, over which it slips; and that it is finally killed and digested by an acid fluid which is secreted in the lower part of the pitcher. That this fluid can really digest meat and other soluble nitrogenous matters, the experiments made by Sir J. D. Hooker, and recorded in his address to the British Association at the Belfast meeting in 1874, have fully proved.

There is another kind of Pitcher-plant in which the structure of the pitchers is rather different. These are found in plants of the American genera *Sarracenia* (the Side-Saddle Flower) and *Darlingtonia* (the Californian Pitcher-plant), Fig. 4, p. 245, and the pitchers, instead of being merely appendages of the leaves, are constructed out of the leaves themselves. These spring from the ground in tufts, and are trumpet-shaped, and provided with lids, which in some species stand erect, and permit the entrance of rain, while in others the lids, being nearly closed, prevent the rain from entering. The inside of the pitcher is very beautifully adapted for the capture of insects. The mouth and underside of the lid are provided with honey-secreting glands (absent in some species, and not always at work in others), which act as a lure for the prey, and which in some cases extend down the outside of the pitcher to the ground, as if to more effectually show the unfortunate victims their way to destruction. Then comes what Sir Joseph Hooker terms a conducting surface, composed of short, conical, slippery spines, pointing downwards, which make a downward passage easy, but prevent return; next is a glassy surface which affords no foothold; and finally a surface studded with needle-like converging hairs pointing downwards and effectually retaining the captured animal. The pitchers often, if not always, contain a fluid, which in some cases is composed—in part at least—of rain-water, and in which the insects decompose. Whether any digestive or solvent liquid is secreted appears to be uncertain. There can be no doubt, however, that insects are caught in large numbers, and that their bodies provide some kind of food for the plant. In the upper left-hand side of the page engraving (Fig. 4) are shown three pitchers of *Nepenthes*. The long stalk springing from the tip of the leaf by which the pitcher is suspended, and the strong ring which strengthens the mouth, are well seen in the central figure. To the right of this is a group of the pitcher-shaped leaves of the Side-Saddle Flower (*Sarracenia*), which derives its name of side saddle from a fancied resemblance in the shape of the flower. Below these are the very curious pitchers of the Californian Pitcher-plant (*Darlingtonia*), whose mouths are almost, though not quite, closed by the hood-like lid. The two leaf-like lobes projecting from below the hood serve as lures for insects, being orange-coloured, and covered on their lower surface with honey. In the right-hand lower corner of the plate are two kinds of Sundew (*Drosera*), the one in front being the Round-leaved Sundew, some of whose leaves have the tentacles expanded, while others have them curved in over their prey. In the opposite corner is a plant of the Venus' Fly-Trap (*Dionæa*), with some of its leaves closed over captured flies. The plant partly submerged in the water is one of the Bladder-worts (*Utricularia*, p. 103), the bladders on whose leaves are thought to form traps for various small aquatic animals, whose bodies, doubtless, serve to nourish the plant.

These are only a few of the various plants now

known as flesh-eaters, but they are the best known, and those in which this property, once thought peculiar to animals, is best seen. This faculty was at one time doubted, but we think that the facts mentioned fully establish the theory that some plants at least are really carnivorous.

## A PIECE OF GRANITE.

By J. H. Collins, F.G.S.,

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Of all the different kinds of stone used in the construction of public buildings, especially docks and bridges, none is more beautiful, more durable, or better known than granite. My acquaintance with granite began at a very early age. My father was a "statuary and mason," and among my earliest recollections are those of men sawing and chipping and polishing pieces of different kinds of stone in his workshop; and here, one day, when about five years old, I saw my first specimen of a stone that glittered wonderfully in the sun, and which I was told was granite.

Soon after, my father removed from London to Staffordshire, and I saw no more granite for several years, for we lived at Bilston, surrounded by coal-pits, and iron-works, and sandstone quarries.

Some years afterwards, when still a boy, I picked up on the newly-macadamised road near our house, a few pieces of stone which seemed more brilliant than usual, and carried them in to my *fidus Achates*—an old workman who never refused to talk to me in my father's time—and he told me it was granite.

He did more than this—he gave me the first (and only) *viva voce* mineralogical lesson I have ever had. Nothing could be more accurate than his teaching proved to be, and I still think, after teaching the science for ten years, that no more appropriate method of commencing the study of mineralogy could be devised. Let me transfer his lesson to these pages. He first asked me if I had a knife, and, fortunately, it happened not to be lost. Opening it, he called my attention first of all to a fresh fracture of the stone:—

"You see these dark, shining plates that I split up into thin leaves with the point of the knife?"

"Yes."

"Well, that's mica" (he called it *mikey*, but this turned out to be unimportant). "Now, see here. These smooth-faced pieces of pink stuff here are so hard that I can only just scratch them with the sharp point of the knife. Well, that's felspar. You may know it, because whenever it breaks it shows these flat, shining faces, and you can just manage to scratch it with a knife."

I said I thought I should know felspar again.

"Now, look here. These here glassy-looking grains between the pieces of felspar are called quartz. If you look close, you'll see they've got no flat faces where they break—they always break rough. And you can't scratch these with the knife—they're as hard as di'monds." I found out afterwards that this last statement about the diamonds was not strictly correct, but, however, I couldn't scratch the quartz grains with the knife, and I told him I thought I knew it as well as the others.

He then went and looked about the yard for various kinds of pink granite and grey, coarse-grained and fine, and made me point out to him the three constituents—quartz, felspar, and mica—which I found I could do perfectly well after a few trials.

"Now," he said, "all granite's made up of them three," and as it was now half-past five, he put on his jacket and left work.

If those of my readers who do not happen to know the constituents of granite will carefully examine the next piece they get hold of with the aid of a good penknife and the old man's lesson, they too will have learnt a pleasant and useful lesson in mineralogy. Since that time I have examined granite buildings in most of the principal towns of Britain, from Liverpool to Sheerness, and from Glasgow to Penzance. I have studied granite in docks and in bridges, in the museum, the mason's yard, and in hundreds of quarries, and from all parts of the world, and essentially I have found the old mason's words perfectly correct.

There are, however, many different kinds of granite—differing more or less in appearance, in composition, and in origin—and I think some of the facts in relation to them may be of interest to the readers of these pages. The most obvious difference is that of colour. In the construction of the Thames Embankment, for instance, pink granite from Mull was largely used for the lower

courses, while the upper portion is composed of grey granite from Cornwall and from Aberdeen. The beautiful pink columns of polished granite which ornament many of the club-houses of Pall Mall are mostly from other quarries in Aberdeenshire. Suppose we examine a bit of this pink granite. The pink itself is soon seen to be the felspar, which has a rich colour throughout. Some of the separate masses are occasionally as much as one inch across. Now examine these glassy grains of quartz. They are everywhere of a pale smoky tint, and the flaky mica is almost black.

Now turn to the grey Cornish granite. Here the felspar is of a pale grey, almost white tint, while the quartz is still somewhat smoke-coloured, and the mica is black. Some of the Cornish granite is very fine-grained, the particles of the respective ingredients being so small as to be scarcely distinguished without a magnifier; but generally it is somewhat coarser in grain than the grey Aberdeen granite. Among the fine grains, too, are often seen long, square-ended masses which also appear to be felspar—as indeed they are (Fig. 1). These are called by the quarrymen "horses' teeth," and the granite in which such large crystals occur is known to geologists as "porphyritic granite." Some of the finest known is obtained at Lamorna Cove, near Penzance, where I have occasionally seen "horses' teeth" twelve inches long and four inches wide.

On close examination of the Cornish granite, we often find two distinct kinds of mica—one dark-coloured, the other almost white—and sometimes also two distinct kinds of felspar; and similar differences are observable in the granites of Mull, Antrim, and elsewhere. Still more careful investigation often reveals the presence of crystals or grains which do not appear to be either quartz, felspar, or mica. Here, for instance, is a very dark green grain, almost black, in a piece of Aberdeen granite, which is softer than the felspar, but still much harder than the mica, and which often exhibits somewhat of a fibrous character. This is *hornblende*—a mineral of immense importance in geology, but which is often extremely rare, and still more often entirely absent from ordinary granite. It is, however, extremely common in the so-called syenitic granite of Guernsey and Leicestershire, and of the peninsula of Syene, in Egypt. The fine obelisk known as Cleopatra's Needle is a good specimen of this syenitic or hornblendic granite.

See these black shining crystals in this piece of Cornish granite. You may easily break them with the point of the knife, for they are extremely brittle, but scratch them you cannot: they are

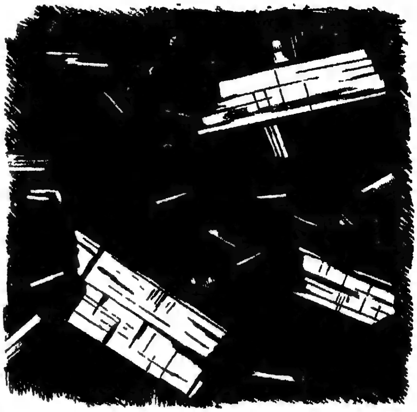


Fig. 1.—Section of Cornish Granite, showing Felspar, etc.

even harder than the quartz itself. They are black tourmaline—the *schorl* of the Cornish and of the German miner. In Cornwall, schorl often occurs in the granite of the mining districts in such quantities as at last entirely to displace the felspar and mica, when the rock, now composed only of quartz and schorl, is known as "schorl rock" or "schorlyte."

The most interesting specimens of granite to the mineralogist do not generally reach the builder at all, as they are what he calls "unsound." The quarryman in breaking down the blocks sometimes comes across a cavity in the solid rock, which is lined with brilliant crystals. In the Antrim quarries, for instance, such cavities are often lined with the most beautifully distinct and perfect crystals of each of the constituent minerals. In the solid granite all appear jumbled together: each compresses the others out of their proper shape; but in the space afforded by the cavity each appears in its own proper form, and exhibits its own individuality.

Fig. 2.—Crystal of Quartz.

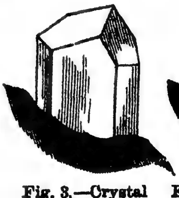


Fig. 3.—Crystal of Felspar.

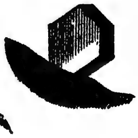


Fig. 4.—Crystal of Mica.

I have such a cavity before me now, and I have sketched some of the crystals as they appear. Fig. 2 shows two crystals of the quartz, Fig. 3 a crystal of felspar, and Fig. 4 a crystal of mica.

But the chief mineralogical interest of such

cavities lies in the fact that they often contain crystals of the rarer constituents of the granite, which would not be discovered in the general mass—such, for instance, as the beryl, the emerald, and the topaz, all of which have been found in the Antrim granite. In Brazil a great deal of the granite contains numerous small garnets. In Cornwall and in Bohemia, crystals of iron pyrites, of oxide of tin, and many other minerals, are frequently met with.

In all mining districts where granite occurs, a distinction is made between "quarry granite" and "mine granite." The first is the beautiful solid material already described, which may be worked to a fine surface, and of which large blocks are obtainable. The second is in a great many instances stained with shades of red, brown, or yellow, contains many extraneous minerals, is cracked in all directions, and the felspar at least is always more or less softened and decomposed. The alteration seems to be due in most if not all cases to the circulation of mineral solutions in fissures produced by movements of the ground from subterranean action, and not, as formerly supposed, to the action of the atmosphere or of rain-water. The gradual change of the felspar crystals may in many instances be traced from the fissure inwards to the solid granite—the amount of change becoming progressively less as the distance from the fissure is increased.

In some parts of Cornwall and Devon this alteration of the granite has reached an extreme point. The whole of the felspar over large areas has been changed into a perfectly white clay (*kaolin*, or china clay), and consequently the granitic mass is so soft that it may be dug out with a pick or shovel with the greatest ease. This decomposed granite—or *Carclazyte*, as it has been called—is at the present time largely worked in Cornwall and Devon for several useful purposes. The soft mass is broken down with heavy picks, the decomposed felspar or "kaolin" washed out from the almost unaltered quartz and mica by a stream of water, dried in the open air or in large covered drying-sheds, and shipped away in large quantities—about 200,000 tons yearly—for the uses of the potter, the paper-maker, the calico-sizer, and other manufacturers.

Another kind of granite which occurs in some parts of Cornwall, but by no means so abundantly as the china-clay rock, is that known as China Stone, or *Petuntzyte*. This is composed of white quartz, and of felspar only partly decomposed, without mica—or only a very little white or pale greenish-yellow mica, of the kind called by mineralogists *Gilbertite*. While in the quarry, this China Stone is very soft and easily wrought, but after exposure to the air it becomes somewhat harder, and the decomposition does not seem to proceed farther if the stone has been well selected.

A great deal of this "St. Stephen's Stone"—so called because it is chiefly raised in the parish of St. Stephen's—has been used for church building in Cornwall for three or four centuries, and some of it still retains the tool-markings after this long exposure to a very moist atmosphere. The chief use of this stone at present, however, is in the Staffordshire potteries, where it is ground up to a fine powder, and mixed with Cornish clay for making china; hence its modern name, China Stone.

Within the last quarter of a century a great deal of attention has been paid to the origin of granite. Unlike limestone, it does not occur in regular wide-spread beds; rather it seems to have been forced up from great depths through the superincumbent strata in a more or less fluid, or rather pasty, condition. Occasionally, indeed, it seems to have been formed in Nature's subterranean laboratory by the alteration of deep-seated stratified rocks, when it has a more or less regular bedded character. Usually, however, as in Cornwall, where its junction with the altered clay-slate (*killas*) can be examined, it is seen to penetrate this in long, irregular points and veins. These veins of injection sometimes inclose small portions of the "killas," which appear to have

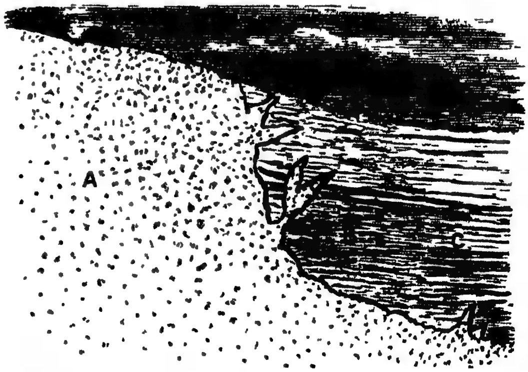



Fig. 5.—Granite penetrating and metamorphosing Clay-Slate into Tourmaline Schist. (A) Granite; (B) Tourmaline Schist; (C) Clay-Slate.

been caught up by the granite while in a fluid or semi-fluid condition. Fig. 5 shows the mode in which the granite penetrates and alters the clay-slate in many parts of Cornwall; A is the main

mass of granite, sending out veins into the adjacent slate; B is the slate in the immediate neighbourhood of the junction, which has been altered into tourmaline schist, gradually passing into the unaltered slate (locally termed *killas*), beyond the influence of the granite. Fig. 6 shows veins of granite traversing a hill of *gneiss*, a rock composed of the same constituents as granite, and only differing from it in the arrangement of the particles of of the Pyrenees traverses tertiary limestones. The consolidation of the granite has also taken place at very different depths. Mr. Sorby, by a masterly method of combined mathematical and microscopic investigation, which he devised in 1857, has shown, for instance, that, assuming a temperature of a dull-red heat as that which on many accounts seems the most probable, the granite of different parts of Great Britain was

Fig. 6—Showing Veins of Granite traversing Gneiss.

quartz, felspar, and mica, which here appear in thin, somewhat irregular layers, instead of being sprinkled indiscriminately throughout the mass.

A careful examination of such junctions as are illustrated above, shows that the intrusion of granite into the stratified rocks has taken place in different countries, at many different times. Thus the granite of Leinster was irrupted into Cambrian and Lower Silurian rocks; that of Devon into carboniferous shales; while the granite consolidated at depths of from 32,000 to 78,000 feet. Its appearance at the surface, and even on high ranges of mountains, is, of course, due to a subsequent upheaval, and the denudation or wearing away of the superincumbent rock by such natural agencies as rain, frost, ice, and the waves and currents of the sea acting through immense periods of time. Such are some of the most obvious points of scientific interest connected with a piece of granite.

## THE COLOURS OF ANIMALS.

By William Ackroyd,

*Fellow of the Institute of Chemistry, etc*

By the modern doctrine of selective absorption, all that variety of colour which beautifies animate and inanimate nature is accounted for in a very simple manner. We have seen (p. 192) that the light of the sun consists, roughly speaking, of seven colours—red, orange, yellow, green, blue, indigo, and violet; if, then, when light falls on an object, any of these constituents be

absorbed, the remainder of the light which reaches the eye will give one the sensation of colour. To take a typical example: A brick house has its quality of redness, because, of all the light which falls on it from the sun, only red, and perhaps a little orange, is reflected and received into the eye; the remainder of the light—*i.e.*, yellow, green, blue, indigo, and violet being absorbed or kept back by the surface of the bricks; hence the quality of the light absorbed determines the hue any substance shall have.

We have here to deal with the animate portion of nature—with the striped zebra of African wilds (Fig. 1), the fallow deer of English parks, and the tiny ermine of Arctic regions—a field so extensive that we can only treat the subject in a very general sort of way. In order that this treatment may be as instructive and suggestive as possible, let us describe, first, certain physical facts which are best studied with specimens that are inorganic, dead, and of known chemical composition. Then, with the principles learned in this way, we shall be in a position profitably to study the organic and animate portion of nature.

Certain compounds of oxygen with other elements—*i.e.*, oxides—are coloured, as, *e.g.*, those of the metals zinc, lead, and mercury. Their colour is strangely affected by rise of temperature. Thus, to take "mercuric oxide": orange-yellow at the ordinary temperature, it changes colour when heated, and becomes orange, red, and brown successively; and it is possible to form a progressive scale of this change, as the writer finds* that the alteration in appearance is the result of the progressively increased absorption of the rays which have their place at the violet end of the spectrum, so that the proportion of rays at the red end of the spectrum which are reflected rises higher and higher. At last they likewise are absorbed, and the end is complete absorption, or blackness.

PROGRESSIVE SCALE OF COLOUR-CHANGE.

| | | | | |
|---|---|---|---|---|
| Heating or Expanding. | ↑ | Black.<br>Brown.<br>Red.<br>Orange.<br>Yellow.<br>White. | ↓ | Cooling or Contracting. |

In view of certain analogies which subsist between these inorganic colour phenomena and those of the organic kingdom, we shall use this scale as a means of reference in our study of the latter. It will be noted that we have the minimum of absorption at one end and the maximum at the other.

The subject of animal coloration is a comparatively new one, literally in its infancy, for it has not passed that qualitative stage which marks the childhood of every science. The only instrument we need therefore use is the naked eye—an instrument most delicate in its perception of variations in tint, when it is normally constituted and has been properly educated. In seeking, however, for subjects, we must employ some discrimination, for one could deduce nothing from making any number of observations of piebald horses or domesticated rabbits. To detect uniformities, and so to form laws, we must restrict our observations to animals comparatively wild and in a natural state, or to those upon which domestication has had little or no effect. We may profitably further circumscribe our field of observation by confining our attention at first to the Mammalia, or that large class of animals which as a rule suckle their young, and have hairy coverings, besides other peculiarities too technical to mention here. Well, the first very general peculiarity one observes is that the ventral portions of the body are lighter coloured than the dorsal—*i.e.*, the back has a colour which stands nearer the black end of our scale than that possessed by the abdomen. For example, to take the squirrel, which naturalists call *Macroxus rufogaster;* its back is brown, whilst its belly and breast are red—a step nearer the white end of the scale. The same peculiarity may be seen in the common ass, whose dorsal parts are decidedly darker than those that are ventral. It may be observed in most of our cows; but to see how general this peculiarity is, one has need to go through a well-stocked museum, where, with a few exceptions, the rule seems to be pretty general.

This darker dorsal portion may be uniformly coloured, as in the majority of instances, or variegated by spots and stripes; and it is remarkable that where there is striping we get an approach to and in many examples complete symmetry of marking. Examine the markings on the head of a Bengal tiger. It will be found to approach a geometrical pattern for symmetry, the stripes on one side of the middle line beautifully balancing those on the other. The same symmetry of pattern is observable in the zebra, Indian tapir, aard-wolf, and even in some of our domestic cats.

Among the higher beings such as those we are now dealing with, there is an "axial" part of the

* "Metachromatism or Colour-Change," *Chemical News*, vol. xxiv., pp. 76, 77.

body from which branch off two pairs of limbs—the arms and the legs, and in continuation of this axial portion we find a tail. These appendages are for the most part grasping or locomotive organs; and there is this peculiarity in their colouring—the body. Fully 94 per cent. conform to the rule. Brown horses seem invariably to have black tails.

A very curious fact respecting animal coloration is that of sexual difference. It has often been asserted by naturalists that males are "brighter-

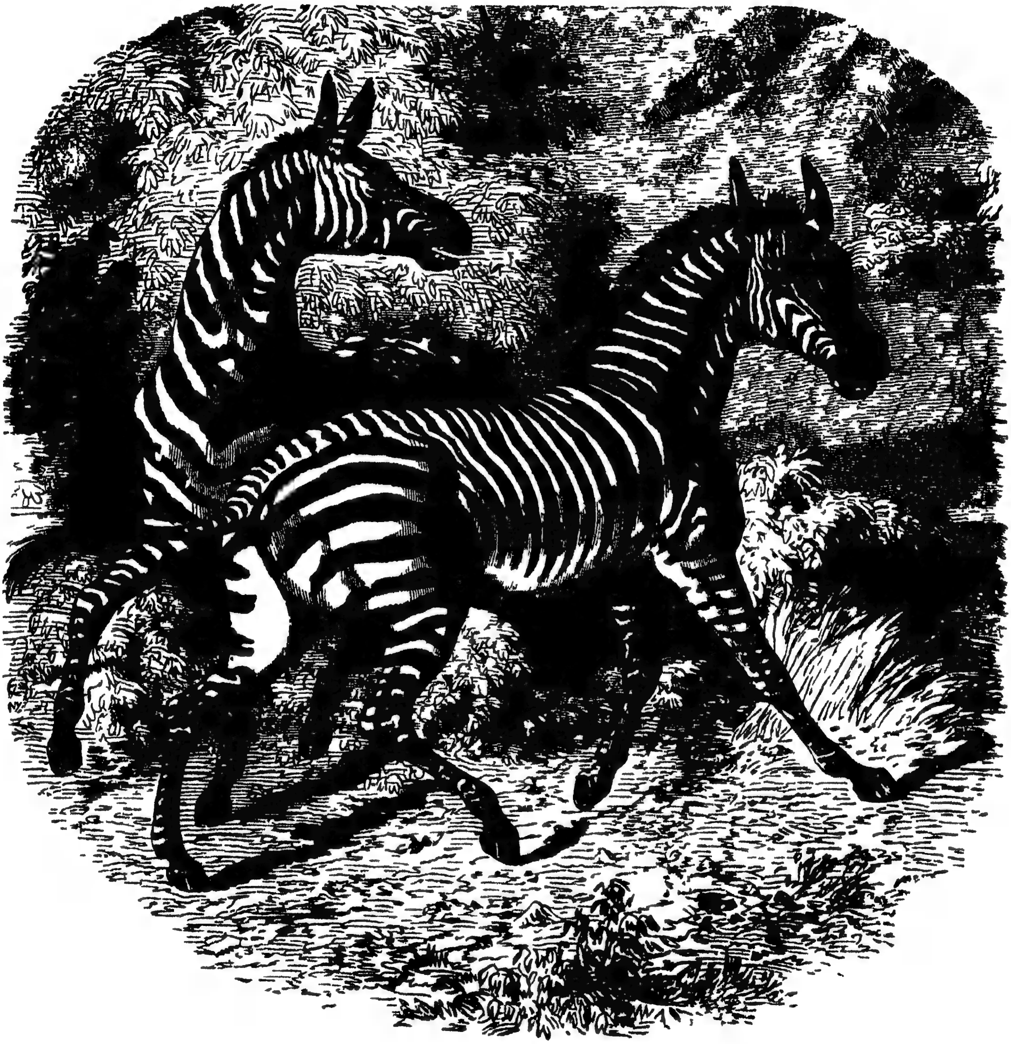


Fig 1.—Zebras

they are more absorptively or darker-coloured than any other parts of the body. Especially is this the case with the tail; thus, in the squirrel already referred to, whilst the belly and back are red and brown respectively, the tail is black. The following observation, often made by the writer, may be easily repeated by the reader. Make a stand at some busy crossing, and of all the horses which pass you in a given time, ascertain the percentage in which the tail is darker than the axial part of

coloured" than females. Now "brighter-coloured" is rather a vague expression, and open to grave misconception. We would therefore substitute for it "darker-coloured" in the sense in which we have so far employed this phrase—viz., that of a colour resulting from a greater absorption of light. With this slight but necessary alteration, the law of sexual difference will stand thus: *The males of a given species are darker-coloured than the females.*

The following table in support of this law is con-

structed from data supplied by Darwin's "Descent of Man." It is necessary to mention that "F" stands for female and "M" for male; moreover, that blue and green are interpolated between white and yellow in the colour scale, for a reason given further on :—

| | White. | Blue. | Green. | Yellow. | Orange. | Red. | Brown. | Black. |
|---|---|---|---|---|---|---|---|---|
| MONKEYS. | | | | | | | | |
| 1 Ruffed Lemur (*Lemur macaco*) | ... | ... | ... | . | ... | ... | F | M |
| 2 Black Howler (*Mycetes nige*) | .. | ... | ... | F | ... | ... | ... | M |
| 3. White-headed Saki (*Pithecia leucocephala*) | ... | ... | ... | ... | ... | ... | F | M |
| 4. Chuva Spider Monkey (*Ateles marginatus*) | F | ... | ... | M | ... | ... | . | ... |
| 5. Hoolook Gibbon (*Hylobates hoolook*) | ... | ... | ... | ... | ... | ... | F | M |
| 6. White-thighed Monkey (*Semnopithecus chrysomelas*) | ... | ... | ... | ... | ... | ... | F | M |
| RUMINANTS (*Chewers of the Cud.*) | | | | | | | | |
| 7. Indian Antelope (*Antelope bezoartica*) | ... | ... | ... | ... | ... | ... | F | M |
| 8. Sable Antelope (*Hippotragus niger*) | ... | ... | ... | ... | ... | .. | F | M |
| 9. Hartebeest (*Alcelaphus caama*) | ... | ... | ... | ... | ... | ... | F | M |
| 10. Nylghaie (*Boselaphus pictus*) | ... | ... | ... | F | ... | ... | .. | M |
| MARSUPIALS. (*Pouched Animals.*) | | | | | | | | |
| 11. Red Kangaroo (*macropus rufus*) | .. | F | ... | ... | ... | M | ... | ... |

The uniformities of colouring which we have so far sketched out, as seen in the mammalia, will be likewise found in birds and reptiles, and even in some of the lowest orders of animals—those without back-bones, or *Invertebrata*, as they are termed. Thus the symmetry of marking is seen strikingly in insects. Catch a butterfly, and examine the disposition of its colours and markings. No matter what the species, it will be found to have the ornamental pattern of one side exactly corresponding to that on the other (Fig. 2). Indeed, this "bilateral symmetry," as naturalists call it, is perhaps in no case better seen than in that of these lovely insects.

Fig. 2.—Peacock Butterfly.

The darker colour of the dorsal than of the ventral portions of the body may likewise be seen in birds, and extremely well in those which frequent the water—web-footed birds. Nor does the law of sexual difference fail among birds and reptiles, as the following few facts, again taken from the "Descent of Man," will show :—

| | White. | Blue | Green. | Yellow. | Orange. | Red. | Brown. | Black. |
|---|---|---|---|---|---|---|---|---|
| BIRDS | | | | | | | | |
| Stork of genus Xenorhynchus eyes | | .. | .. | F | ... | ... | ... | M |
| Hornbills (Buceros) . . . . „ | F | | .. | ... | ... | M | ... | ... |
| Condor . . . . . . . . „ | ... | ... | ... | ... | ... | F | M | ... |
| LIZARDS. | | | | | | | | |
| Calotes nigrilabris . . . lips | ... | ... | F | ... | ... | ... | ... | M |
| Zootoca vivipara (underside of body) | ... | .. | F | ... | M | ... | ... | ... |
| SERPENT. | | | | | | | | |
| Dipsas cynodon | ... | ... | .. | ... | ... | F | ... | M |

In speaking of the limbs and tail, it will not require much thought to see that those belonging to a mammal have exactly corresponding parts in a bird, and taking the squirrel (*Macroxus rufogaster*) and a robin redbreast as examples, one might make some such comparison as the following :—

| SQUIRREL. | | REDBREAST. | |
|---|---|---|---|
| Back | brown. | Back | brown. |
| Belly and breast | red. | Belly | light coloured. |
| | | Breast | red. |
| Front-leg flanks | inclined to black. | Wings | dark brown. |
| Tail | black. | Tail-tip | dark brown. |

Such a comparison is not fanciful, as the deeper teaching of anatomy tells us that a mammal's front legs are the appendages which correspond to a bird's wings. The correspondence of the other parts is manifest even to common observers. The point, however, to be noticed is that the wing and the tail-tip are darker than the rest of the body; or as we expressed it in the case of the Mammalia, the appendages are more absorptively or darkly coloured than any other part of the body.

The causes at work producing these uniformities in colour are hidden from us, and to discover them will doubtless furnish much work for future investigators. There are, however, phenomena which seem to give us an inkling as to what they may be, and these phenomena we will proceed to describe.

With the approach of winter in the Arctic regions, there is a gradual change of colour in many of the animals—*e g.*, the Arctic fox and ermine,* and they become as white as the snow they tread upon. Even certain quadrupeds which do not take on a white winter dress become, according to Pallas, of a paler tint. This celebrated naturalist states that in Siberia such a change occurs in the wolf, domestic horse, domestic cow, musk-deer, elk, roe, reindeer, and many other animals. The roe, for example, has a red summer coat and a greyish-white winter coat. Now, it is very tempting to think that the first persistent feeling of cold which these animals experience when the season alters, gives rise to such a change in the skin as is competent to produce an alteration of colour; in other words, that the change is a product of reflex action (p. 176). There are examples of colour-change, in which there cannot be the slightest doubt of this being the case. Thus, the chameleon, about which such wondrous tales have been told, will alter the colour of its coat to

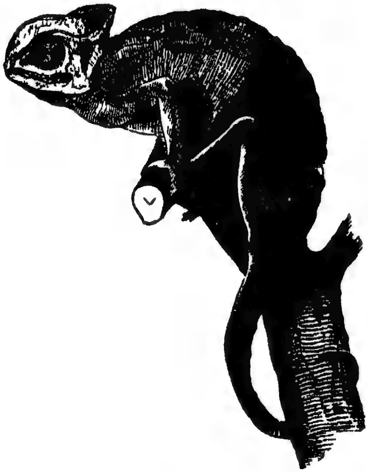


**Fig. 3.—Showing Chameleon under Sunlight, passing through Red and Blue Glass.**

some extent when light is allowed to fall on it. Fig. 3 is illustrative of an experiment on this point made by Bert. The chameleon was placed in full sunlight, care being taken that the light illuminating the fore part of the body should pass through red glass, whilst that falling on the hind part had to pass through blue glass. The body seemed divided into two parts, the anterior of a clear green with red spots, and the posterior of a darkish green. Here, it is evident that the "feeling of light," if one may use the phrase, was transmitted to the central nervous organ, and the disturbance was then reflected back to produce an alteration in the

**Fig. 4.—Showing Chameleon under Lamp-light, with Dorsal Part protected by a Screen.**

appearance of the skin. In another example, a sleeping chameleon was placed under the influence of strong lamp-light, whilst the dorsal part of the body was protected by a screen. In this way the singular appearance given in Fig. 4 was obtained, where the head, neck, feet, abdomen, and tail, are of a darkish green, and the protected portion appears like a brownish saddle.

That colour is regulated by some deeply-seated and symmetrically distributed portion of the organism, such as the nervous system, seems not improbable likewise, when we come to think about those cases of symmetrical colouring which we have already briefly referred to.

In the case of the chameleon, direct experiments have been made which show that, at any rate in this animal, the colour is governed by the nervous system. In one experiment of Bert's, it was found that if by any accident the spinal cord of a chameleon was severed (as at *a* in Fig. 5), the fore-part of the body was green, whilst the posterior became black. Plainly, here the breaking of the nervous continuity caused the dissimilarity of tint

* It would seem that man is not exempt from this change. Captain Markham observes:—"It is a curious fact connected with those who were for a long period absent from their ship, that the hair on their faces was bleached nearly white. The loss of colour was gradual, and although noticed, was never alluded to, each one imagining that his companion's hair was turning grey from the effects of hardship and anxiety. It was only after their return to the ship that those possessing beards and moustaches discovered the change of hue in their own hair. The colour gradually returned in about three or four weeks."—"*The Great Frozen Sea*," p. 376.

between the two parts of the body. Again, in making two or three sections of the spinal cord as at *a b c*, Fig. 6, and then exciting the portion of the spinal cord at *c*, which led to the posterior part

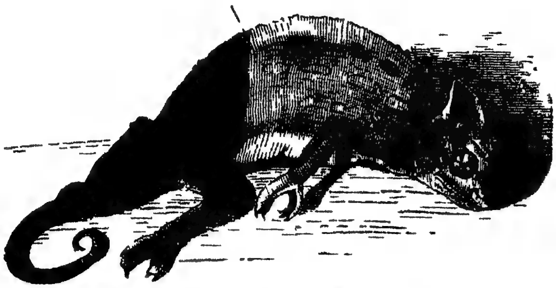


Fig. 5.—Illustrating Bert's Experiment.

of the body, and exciting at *b* that portion of the cord which led to the head, it was found that those portions of the body to which the stimulated nerves led became of a clear green, whilst the part of the body between *b* and *c*, the nerves to which had not been excited, remained of a sombre tint.

It is unnecessary for us here to give the various hypotheses that have been held by investigators, as to the nature of the chameleon's colour-change. Suffice it to say, that it is the opinion of the most recent, M. Bert, that a set of nerves similar in

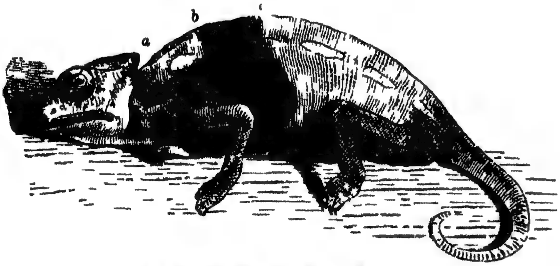


Fig 6.—Illustrating Bert's Experiment.

their working to the *vaso-motor* nerves, are those which play the important part of making the integument vary in colour under suitable circumstances.

Extraordinary changes of tint are seen sometimes when certain fishes die. Pliny narrates that the ancient Romans, who esteemed the gold-fish (*Mullus barbatus*) a great delicacy, would not dine off it until they had seen it die, its exhibition of the various rainbow hues affording them much amusement, and, in fact being one of its chief merits.

Respecting the ultimate nature of this change we can only for the present make surmises. It may, probably, be of the same nature as that inorganic colour-change we have already described; and at any rate there is a striking resemblance between the two phenomena. We have seen that when certain inorganic bodies are heated, they change colour in a particular order, and that when they cool they regain their old tints. Now, the change of structure which we have here may probably be effected by other agents besides heat. It only requires the scratch of a pin, or the slightest disturbance, to change the yellow iodide of mercury into a scarlet modification, and it is conceivable that in the organic world expansion and contraction of the component parts of the organism may be effected by other means and in other ways than those we employ for coloured oxides. Only this we look for, that where we have expansion, there we ought to get increased absorption; where we have contraction, there we ought to have decreased absorption. In the case of the chameleon, it seems a remarkably confirmatory fact that green and yellow are acquired when what we may term the compressing nerves (those which act like Bernard's *vaso-constricteurs*), are at work, and that sombre tints are assumed when the expanding nerves (those which play the part of Bernard's *vaso-dilatateurs*), are concerned.

Again, death in animals is generally accompanied by a sort of contraction, known as the death-stiffening or *rigor mortis*. Now, when fishing mackerel, if the tint of one freshly caught be compared with one that is dying, the former appears of a sort of sea-green, and the latter of a deep blue. That this change denotes contraction is better seen when one compares it with the behaviour of a hot borate of copper bead, which is green, and as it cools and contracts becomes blue. Blue and green were interpolated in the scale given on p. 254 in order to include this borate change.

It may be that ultimately we shall be enabled in some such manner to explain the deepening of tint observed in animals passing from youth to the adult state; the acquisition of grey and white by those passing to old age, and the similar change, bu sudden, which has been brought on at times by great privation or acute distress. In a paper read at the Plymouth meeting of the British Association (1877), the writer attempted to carry this analogy farther, by regarding colour-change as evidence of alteration of *energy*. Energy means the power to do work, and just as we impart energy to water when we heat it—energy which may be turned to useful purposes by means of the steam engine—so we no less impart energy to an oxide when we heat it;

and the colour-change is an ocular evidence of this transference of energy. Applying, then, this idea to the subject in hand, we may regard colour-change, where there is an increase of absorption, as evidence of increase of animal energy; and on the contrary, where there is a decrease of absorption, not for climatic purposes, as evidence of decrease of animal energy. For this purpose our scale would stand thus :—

| | | | | |
|---|---|---|---|---|
| | | Black. | | |
| | | Brown. | | |
| Increase of Animal Energy. | ↑ | Red. | ↓ | Decrease of Animal Energy. |
| | | Orange. | | |
| | | Yellow. | | |
| | | Green. | | |
| | | Blue. | | |
| | | White. | | |

We ascend the scale from less to more absorptive colours when an animal changes from its cubhood to the adult state. To take an example: the young of the Howler monkey, known as *Mycetes caraya*, are of a greyish-yellow; in the second year they become reddish-brown; in the third year they are black all over, save the stomach, and after this the stomach becomes black too. The change is typical, and may be seen in other animals, even in man. Many a man with red, brown, or black hair had, as a child, yellow locks.

On the other hand, when the prime of life is past, when life is on the wane, and energy decreasing, a change is seen in the opposite direction—the hair becomes grey or white. Such a change to greyness has likewise been observed in the fox and dog, horse and hare. To keep up the analogy, one would naturally expect some such change where there is an excessive draught on the vitality, produced by sudden fear or great privation; and it is noteworthy that many of the survivors of the wreck of the *Strathmore* had the colour of their hair temporarily changed by the sufferings and anxiety they had undergone. Black hair became brown and red, and fairer colours were changed to white and flaxen.

We may now conclude with a few words on the uses of these colours to the animals which possess them. There can be no difference of opinion as to the use of a hairy covering, for it evidently serves the same end as clothes by keeping the body warm. Now, we change our garb with the season, as we find by experience that a light, airy suit is much fitter for summer wear than the dense heavy materials we employ in winter. It is not unreasonable to think, therefore, that it would be conducive to the well-being of animals in the Arctic regions if they could be protected against the cold, which is at times so extremely severe as to freeze mercury as hard as a stone. It may be that the winter change to snow-white answers this purpose. Such a supposition receives some support on physical grounds. We know that good absorbers of heat readily give off the heat they have absorbed. A good absorber of heat would therefore be ill-fitted to keep the animal frame in a warm and comfortable state in a cold region. On the other hand, we are equally certain that a bad absorber of heat does not readily part with the heat it possesses. Therefore, a bad absorber of heat would be well adapted for keeping an animal warm. On these grounds, it is not improbable that the badly absorbing white fur is much fitter for winter wear than the dark and heat-absorbing summer coat. The former would economise animal heat at a time when food is scarce and the atmosphere rigorously cold; the latter would readily part with surplus heat when food is plentiful and climatic conditions are comparatively mild.

It is supposed by naturalists that this snow-tint of Arctic fauna is a protective colouring *i.e.*, that an animal is concealed by its resemblance to the snow from the enemy that would prey upon it. Such an idea is in no way inconsistent with the hypothesis of "climate protection" just advanced, but, at the same time, it is beset by what seems to the writer a formidable difficulty. A colour which conceals both the enemy and the prey it steals upon, favours one in the same measure as the other, and would seem, therefore, to be useless.

The dermal covering may be regarded as a sort of heat-economiser which is probably governed by the nervous system; and one can quite understand that if the atmospheric conditions rendered it necessary, the white coat would be retained the whole year round. As a matter of fact, naturalists have found that the changing hare (*Lepus variabilis*) retains its shining white fur in Scotland until the month of March, or even later, according to the temperature of the atmosphere. Taking this view of matters, we may regard that difference of tint between dorsal and ventral parts, to which we called attention in the fore-part of the paper, as due to a similar cause. Thus, the ventral parts being constantly turned towards the cold ground, must, by radiation and direct contact, be constantly in need of a warm covering. Hence, the white abdominal fur may be induced in the same way, and have to serve the same end, as the snow-white garb of Arctic animals.

The sandy colours of many desert-frequenting animals; the green colours of birds and reptiles living in tropical forests; and the remarkable tints of many insects, are regarded as examples in which the colours are protective, by affording concealment either from their enemies or from the creatures they prey upon. It may be that many of these are real cases where protection is derived; some, however, are open to doubt. The chameleon was once considered a fine example of protective colouring, it being roundly asserted to have the power of adapting itself to the colours of surrounding objects with the greatest readiness; and it was thought that it kept out of harm's way in this manner. The wild tales that were told of it by travellers and poets have not been supported by the sober researches of Milne-Edwards, Pouchet, Bert, and others. Its colour-changes have not been found to be so sudden or so extreme as imaginative writers were wont to describe. On this account, the idea of protection, so far as the chameleon is concerned, is now regarded with some disfavour.

Although we must now end our necessarily brief survey of the colours of animals, we have not dealt with a tithe of the matters which rightly come within our province. In treating of a subject wherein much freedom of thought is permitted, our aim has been rather to be suggestive than dogmatical, and for further information we would refer the reader to the great book of Nature; or if his pursuits will not permit of his making independent observations, then we would refer him to the next best thing—the writings of Darwin and Wallace, which are excellent storehouses of fact.

## SCIENCE AND PHOTOGRAPHY.

BY JOHN THOMSON, F.R.G.S.

CHEMISTRY and optics are the parent sciences to whose union the world is indebted for photography. Brought to light during the early part of this century, partaking of the characteristics of both parents, photography has pursued an independent course, opening up new fields of scientific research, and materially aiding the progress of discovery. No discovery of modern times has found a wider sphere of usefulness, contributed more liberally to our store of accurate knowledge, or has a more important part to play in the future history of science. A retrospective glance at what photography has already accomplished will unfold some phases of its development, which read more like romance than reality.

About the middle of the sixteenth century Porta's camera-obscura and the chloride of silver discovered by Fabricius were the optical and chemical germs of photography. Porta's camera projected images of outer objects through a small aperture pierced in the doorway of a dark chamber on to a screen. It was only necessary to render this screen sensitive to light, so that the images might be imprinted on its surface, to complete the discovery of photography. Fabricius discovered the sensitising agent in a salt of silver, and it is, to this day, on silver compounds that photography depends for its finest results.

Here then, three centuries ago, were the rudimentary camera and chemicals, but it was not until the year 1801 that the scientific union of these was effected by the labours of Wedgwood. This distinguished experimentalist, aided by Sir Humphry Davy, succeeded in producing impressions of images projected by his solar microscope upon a screen of paper or leather rendered sensitive to light by a coating of silver chloride or silver nitrate. These images were impressed in a dark chamber, and could be viewed only by weak artificial light, as no means was discovered of fixing the pictures so obtained.

At this step the progress of discovery was arrested; nothing further being done until Niepce, Daguerre, and Talbot, men of a new generation, came to solve the problem of permanent sun printing. These three savants laboured independently; each accomplishing his task in his own allotted way. Niepce found that bitumen became insoluble after exposure to light, and taking advantage of this discovery obtained impressions of engravings on paper, by sun printing. Bitumen, however, was not sufficiently sensitive to be of use in the camera.

Daguerre and Talbot's researches were rewarded by the discovery of the processes which bear their names. Daguerre rendered silver plates sensitive to light by the fumes of iodine (Fig. 1), and discovered that a latent, invisible image was impressed by the

camera, which he evoked by the vapour of mercury. Talbot's earliest photographs were produced on paper charged with a solution of silver chloride. Impressions of leaves and flowers were obtained by exposing this paper to the solar rays, under the objects to be copied.

Talbot's calotype process, communicated to the Royal Society in January and February, 1839, gave a new and most important direction to his researches. The process embraced the discovery of the latent image, and mode of its development. Calotype paper was so exalted in sensitiveness that it was at once available for portraiture in the camera. Impressions obtained direct in the camera were termed negatives, and from these Talbot produced positive copies in the photo-printing press.

Daguerre's and Talbot's discoveries were nearly coeval. They were both announced in January, 1839, but Daguerre's method was not made public until August of that year. It was not until 1840 that the first portraits were taken in the camera, on Daguerrotype plates, by the employment of bromine vapour, to increase their sensitiveness, an improvement due to Mr. Goddard,* and by Talbot's calotype process.

Talbot soon applied his process successfully to photo-micrography; on this subject, he said:—"Contemplating the beautiful picture which the solar microscope produces, the thought struck me whether it might not be possible to cause that image to impress itself upon the paper, and thus to let Nature substitute her own pencil for the imperfect, tedious, and almost hopeless attempt of copying a subject so intricate."

Talbot carried his scientific researches in photography further, each step being crowned with a greater measure of success. He so exalted the sensitiveness of his calotypic paper as to enable him to obtain a perfect impression of a printed sheet attached to a rapidly revolving disc. This disc was illuminated for an instant by a flash from the Leyden jar of an electric battery. The most important result of Talbot's scientific labours in connection with photography, was his method of producing a photo-engraved copper or steel plate fit for the printing press. His first successful experiments in this direction depended upon the remarkable property, already mentioned, of bitumen in becoming insoluble when exposed to light. This plan, however, was set aside in favour of a mixture of gelatine and bichromate of potash in water, a discovery due to Mungo Ponton and Becquerel. This mixture proved much more sensitive to the solar rays, and, like bitumen, became insoluble when exposed to light. The discovery of this property in gelatine sensitised with bichromate of potash laid the foundation of all the known photoglyphic processes of the present day.

Talbot's process of photo-engraving, although in his hands successful, was hedged round with difficulties in the hands of ordinary operators. These difficulties have been overcome, and new or modified methods have grown out of the old, so that it is now possible in some measure to supersede the engraver, and to produce printing blocks fitted for book illustration which may be set up and printed with type in a steam press.

It is impossible to over-estimate the boon conferred on science and art by this new mode of diffusing knowledge. One element of success in the new departure in engraving is purely commercial —it is cheap; it is also good and true. Where facts in science have to be recorded it stands alone, and is so incontestably correct as to be of the utmost value in furnishing evidence in courts of law. Photographs of this sort furnish trustworthy *data* for geography, ethnology, chemistry, and a host of other sciences too numerous to catalogue; also phenomena invisible to the naked eye are brought within the range of our senses by such sun messengers as these. But to be more accurate, it will be necessary to make a brief survey of some of the most prominent applications of photography to science.

It is difficult, nay almost impossible, to limit the scope of geography, it embraces so many branches of science, but it is within the mark to say that photography finds a field of usefulness in nearly all phases of this fascinating pursuit; and that the relation between sun picturing and science becomes closer year by year, as our knowledge advances.

The operations of photography have become so simple and are so well under control in the hands of the operator, that the camera and sensitive plates, or films, form, or ought to form, an important part of the outfit of every exploring expedition. The apparatus may be carried in very small compass, and the plates are available for picturing the geological and topographical features of a country, as well as the physical characteristics of its inhabitants, its botany, and its zoology. Such sun records of travel, in order to meet the requirements of science, should be done to scale, so that the

* Tissandier: "History and Handbook of Photography," p. 350, Appendix A.

*savant* may pursue his studies at leisure when a series of photographs are placed before him.

One of the most delicate and subtle applications of photography will be found in its connection with spectroscopic analysis, an experimental process to which the chemist and astronomer are alike indebted for some of the most startling discoveries of our time. Wollaston was the first to observe the presence of certain black lines occupying fixed positions in the solar spectrum, but to Frauenhofer belongs the honour of first carefully measuring and mapping them. The subsequent discovery, by Kirchoff, of the cause of these lines, gave a great impetus to the new system of analysis. It was the discovery of a new language of which these lines were the visible characters. Kirchoff proved that the lines in the solar spectrum were caused by the presence of certain gases in the atmosphere of the sun, and of the vapours arising from metals in a state of incandescence. It is white light from the body of the sun piercing those vapours that transmits to our earth evidence of their presence in the solar atmosphere. Photography, by the reproduction of lines in the spectrum which the human eye perceives, and of others which it does not perceive, discloses the presence of known substances, and thus registers this evidence.

In this way Bunsen, Kirchoff, Rutherford, and others, have gained some knowledge of the chemistry of the sun, while Dr. Huggins has succeeded in the still more difficult task of unfolding the secrets of the fixed stars by photographing their spectra.

The differences that exist between solar and stellar spectra, and between the spectrum of one star and that of another, need not be discussed here. It may, however, be said that photography applied to the spectroscope supplies records of these differences in solar and stellar chemistry which will form a basis of reference in future ages, and a means of detecting changes that may occur in the composition of the sun and stars.

Photography, in its relation to the heavens, is not confined to the revelations of the spectroscope. It has been utilised in making a celestial chart by Rutherford and other astronomers, showing the relative positions of stars at any given time. These charts will prove of the utmost value to future generations. Our neighbouring satellite, the moon, has been a favourite object for astronomical photography. It has been impressed in all its phases; so well and frequently has this been done as to impart an ever-widening knowledge of its physical features. Its mountains and valleys are even named, described, and measured, an approximate estimate being formed of the elevation of its masses and depth of its depressions from the length of the shadows cast by the solar light upon its surface. Some of the most recent and wonderful revelations of astronomy are the phenomena connected with an eclipse of the sun recorded by photography.

During the eclipse of May, 1882, photographs were taken of the sun's corona by the members of the scientific expeditions posted at vantage points in Egypt. The negative plates obtained in Egypt of the corona and spectrum of the corona proved most satisfactory. These impressions were taken upon glass plates coated with the most sensitive mixture of gelatine and bromide, or bromo-iodide of silver. This gelatine emulsion has, within the last ten years, completely revolutionised the practice of photography. They (the plates) can be carried about in the dry state without detriment for at least two or three years before being exposed in the camera to receive their impressions. These images, when impressed, may remain latent and invisible on the plates until it is convenient for the operator to bring them out by development. The sensitiveness of these plates to weak radiations of light proved of great value to the expedition; also their being always ready for use.*

The use of photography in connection with the microscope was demonstrated by Talbot; and since his time, the progress of this branch of sun-printing has kept pace with improvements in the instruments and the sensitive plates upon which photomicrographs are taken. Photo-micrographic impressions may be taken either by solar or artificial light, with the aid of the object-glass of a microscope alone. Animal and vegetable tissues are thus rendered on a greatly enlarged scale with the utmost delicacy, and may be photo-engraved for book illustration or for the use of students in class-rooms.

*Micro-photography* is the term applied to the process of reducing images of objects to the smallest possible dimensions by means of photography. This department of our subject was brought to perfection about 1859, when toy microscopic slides were in vogue, some of which contained in the space of a pin's head as many as one hundred portraits of celebrities, which could only be disclosed to view beneath a powerful microscope.

Pigmy photographs, attached to the end of a cylindrical lens, and inserted in jewellery, became

* See *Photographic News*, Aug. 4, 1882.

common enough. But these micro-photographs were destined ere long to serve important ends. During the Franco-Prussian War in 1870—71, the process proved of value when Paris was besieged. Despatches containing three hundred thousand characters were reduced to the space of two inches by one inch. The thin collodion film upon which the documents were reduced was stripped from its glass support, folded up, inserted in a goose-quill, and fixed to the tail of a carrier pigeon (Fig. 4), to be borne in safety across the Prussian lines to the beleaguered city. Afterwards, when the winged messengers had finished their flight, the despatches were placed in an enlarging lantern, and projected upon a white screen, so as to be read and transcribed by press reporters.

Fig 1.—A Cricket Match (*From an instantaneous Photograph by Messrs. Marsh Brothers*)

Since the year 1859, *barometric and thermometric* photo-registers have been in use at Kew Observatory. The apparatus employed has been gradually improved and perfected, while new modes of photo-registration have also been devised. The value of meteorology as a science depends upon the accuracy with which atmospheric changes are registered at regular intervals of time.

Such observations can be made automatically by mechanism aided by the sensitive plate or paper of photography. This has been accomplished in such a way as to establish continuous records of the rise and fall of the mercurial columns in the barometer and thermometer. In order to get some notion of how this is done, it should be borne in mind that above the mercurial column of the barometer there is a clear space of glass tubing. In front of this space a light is placed, and on the opposite side of the tube a metal plate having a slit cut in it of the same width as the column of mercury. Under this slit a band of sensitive paper is unrolled from a drum, and kept continually in motion by an arrangement of clock-work. The light passing through the slit and falling upon the moving band of sensitive papers, prints a line of varying thickness corresponding to the rise and fall of the column of mercury.

By a similar arrangement the rise and fall of the mercury in the thermometer are accurately registered. Meteorological observations are recorded by photography at many observatories in different parts of the world, and the result is that comparisons may be made of the state of the atmosphere at a given time and at stations widely apart, and conclusions drawn regarding the phenomena, or laws of atmospheric disturbance, and the results to be looked for when disturbances do occur in certain regions of the globe.

There are many other ways whereby photography assists in filling out, so to speak, our knowledge. Some of these may receive only a passing notice in this necessarily brief article.

There, for instance, is submarine photography,

successfully pursued with the electric light; and, again, the photography of animals in motion. Mr. Muybridge, an American, and M. Marcy, a Frenchman, have laboured chiefly in this field, taking photographs of animals in motion at regular intervals, in the fraction of a second of time. The object of taking a series of impressions of an animal in rapid motion at brief intervals, is to register the positions of the limbs and play of the muscles at any point between the beginning of a leap, or stride, and its termination. This is done so successfully that a series of these photographs placed in the zoetrope produces, when the instrument is set in motion, a perfect imitation of the continuous motion of an animal, say, in racing, another series in leaping, and a third in hunting and so on. The positions in which the horse in motion have been portrayed by these photographs appear constrained, and are quite at variance with art picturings of animals racing, hunting, and leaping. But although these impressions of a horse at any part of its stride are scientifically correct, they fail to convey the idea of motion. What the artist aims at depicting on canvas is the impression of motion, just what he can see; and he succeeds, because he supplements what he sees by the feeling of motion carried to the brain by the retina. (Figs. 2, 3.) Besides animals in motion, scenes full of active life are now frequently photographed (Fig. 1).

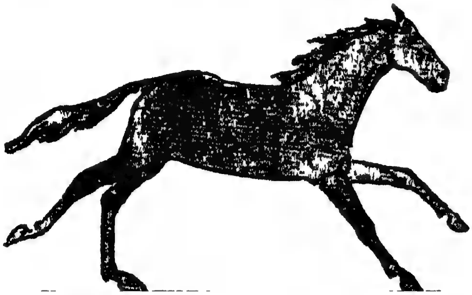


Fig 2.—Photograph of a Trotting Horse.

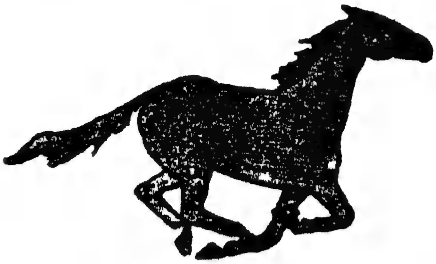


Fig 3.—Photograph of a Galloping Horse.

*Photography in colour* remains still to be discovered. Some approach has been made towards the solution of the problem. Sir John Herschel, in his experiments on the juices of flowers, hoped to find a clue to the mystery, but failed. He tried to impress the solar spectrum on silver chloride, and succeeded in obtaining a faint and fleeting promise of chromo-photography. In his researches, he was followed by Becquerel, Niepce de Saint-Victor, Poitevin, and others, but their labours have come to no practical issue. In this direction photography is thus far limited.

Fig. 4.—Carrier Pigeon with Photographic Despatch.

It is a recorder of the light and shadow of images seen by the human eye, but the camera perceives and notes more and less than the eye. More in the minuteness of its records, less in its relation to colour, and the feeling of motion produced on the retina. Photography breaks down as an interpreter of colour in reproducing the colour values in nature and in art. This negative quality in photography, however, is not without its value to those whose labours are directed to the investigation of the nature of light and colour.

Fig 1.—A Thunder-Storm.

# A THUNDER-STORM.

By William Durham, F.R.S.E., etc.

ALMOST every one must have seen a thunder-storm at some period of his or her life; few, however, have regarded it with intelligent interest as to the cause which produced it or the forces displayed. Some are content with contemplating the sublimity of the spectacle; while others, in ignorant or superstitious fear, seek to hide themselves from the attending danger by shutting it out from their sight.

Those, however, who desire to know more of Nature's works than appears on the surface, while not insensible either to the grandeur of the display or to the danger that accompanies it, will calmly and quietly examine all that happens, and try to find out the cause by patient investigation. With this purpose let us watch the progress of a thunder-storm. The weather has been warm and sunny for some days; people complain of a feeling of depression and heaviness, which they account for by saying "there is thunder in the air"—rather a curious way of putting it, as thunder is usually heard, not felt. No doubt, however, there is something unusual about to happen. Suddenly a dense, dark cloud forms overhead, which rapidly increases in size, rising higher into the atmosphere, and drawing towards it any little clouds that may be scattered about, although they may have been quite motionless before; just like an army preparing for battle gathering in its scattered detachments. Increasing in size and blackness, with an ugly, ragged, and threatening look, the mass of cloud begins to approach the earth, sending out masses sometimes at one part and sometimes at another, but always towards the earth, while little cloudlets hurry to and fro over its surface, like officers marshalling the ranks for a grand attack. The rain now commences to descend, and the first faint beginning of the storm is heard, like the distant growl of some savage animal, low and threatening; flashes of light are seen darting here and there in the midst of the cloud; sometimes the whole mass is lighted up as with a vivid sheet of flame, or the dark edges of the cloud are brilliantly illuminated, displaying its ragged-looking form many times in

succession; the thunder increases in frequency and loudness, sounding like the rattle of musketry mingled with the roar of artillery. As the cloud nears the earth, a flash passes between them, *followed instantly by another flash at some distance; and sometimes we can trace through the cloud a* connection between the two flashes. The lightning varies in appearance: sometimes it is a clearly-defined zigzag line; at other times it forks or spreads into many sharp points; occasionally it becomes a ball of fire, moving at a slower speed than either of the other forms, so that the eye can follow it. Many suppose this ball is a really solid "thunder-bolt;" but it is not so, but only a modification of the other forms of lightning. The storm is now at its height, and rages as a battle among the elements; the thunder roars and crashes overhead with appalling violence, and the vivid lightning flashes on every side. Now is the time of danger. The lightning in its path to the earth bursts through all opposition with irresistible violence: buildings unprovided with lightning-conductors are shivered to pieces like castles of cards and woe to the unfortunate being who chances to be in its path—death is his certain fate, and that in an instant! If the lightning should chance to light on sand, it not unfrequently fuses it in its path, and leaves long rods of a glassy nature as evidence of its fearful energy. This display continues until the cloud has exhausted itself, when it vanishes almost as quickly as it gathered, and we are left with a feeling of relief and freshness.

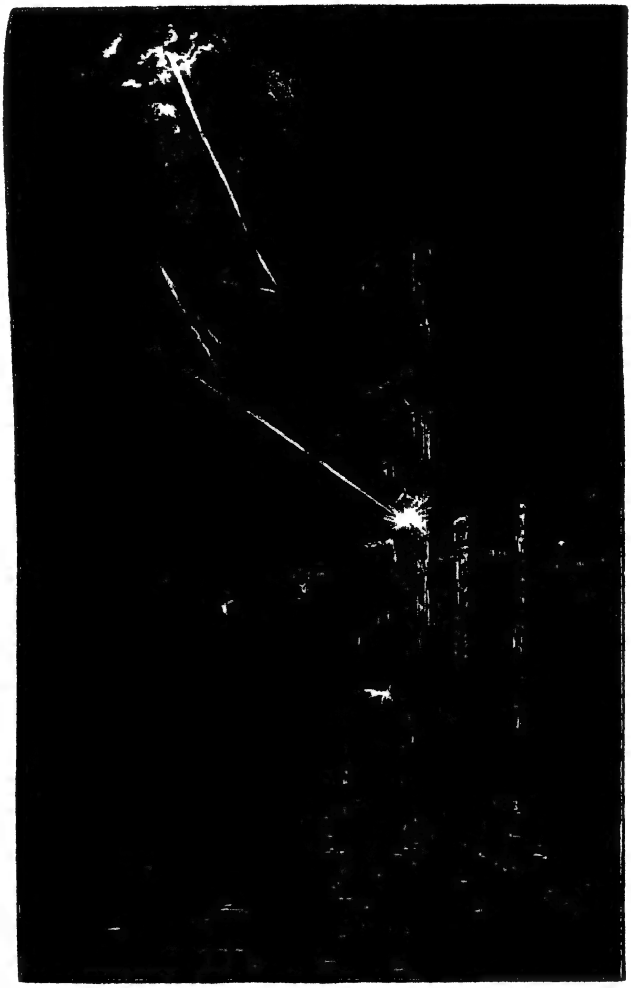


Fig. 2.—Lightning firing a Street Gas-Lamp.

Of all the forces of nature with which we are acquainted, the one that seems most likely to afford

us an explanation of a thunder-storm is electricity. The famous American philosopher and statesman, Benjamin Franklin, was the first to light upon a method of proving this. By means of flying a kite, provided with a sharp steel point on its head, connected with the string, he succeeded in bringing down from a thunder-cloud flashes of lightning, which, he proved, exhibited all the phenomena known to be due to electricity. The experiment is attended with considerable danger to the operator, as was proved by the fact that a Russian physicist repeating Franklin's experiment was struck dead by the lightning; so any one desirous of trying it must exercise the greatest caution. We shall therefore examine the laws and phenomena of electricity so far as they bear on a thunder-storm, and see how far they explain what we have observed. When seeking for the origin of such a grand display, we are apt to look about us for some equally grand cause; but Nature often commences her greatest works in a very modest manner, working for long silently and unseen until she accumulates her forces; and in this case it is so. We must commence our investigation with phenomena so trifling as almost to escape observation.

It is well known that electricity developed by friction first exhibits itself in attracting such light bodies as feathers, &c.; and further that the electricity developed on the glass acts somewhat differently from that developed on the wax. While both attract any light body they are brought near, and one another, yet glass electricity repels glass, and wax electricity wax. To distinguish between these two kinds, we call the electricity developed on glass *positive*, and that on wax *negative*. Therefore, when we speak of positive or negative electricity, we just mean that the former is like that developed on glass, and the latter like that on wax.

Electricity can be conveyed from one body to another by contact; and this affords us the means of making a little testing apparatus to show by what kind of electricity any body is electrified.

Let us take a small pith ball and suspend it by a silk fibre from a stand, as in Fig. 3. On rubbing a glass rod with wax and bringing it near the pith ball, the latter will be attracted like the feather, but immediately on touching the glass rod it will fly off as marked by the dotted lines on the figure. On bringing the excited wax, however, near it after being touched by the glass rod, the pith ball will be attracted by the wax. If we wish, therefore, to know what electricity any body has, we just touch the pith ball with excited glass and bring it near the body; if it be attracted, the body is negative; and if repelled, positive. With instruments constructed on this principle, but of exceeding delicacy, it is found almost invariably that when two different substances are brought into contact, and especially if there be friction between them, electricity is developed — positive on the one substance and negative on the other. And the one *is never developed alone;* wherever there is positive developed, there is also an equivalent of negative, and *vice versâ.*

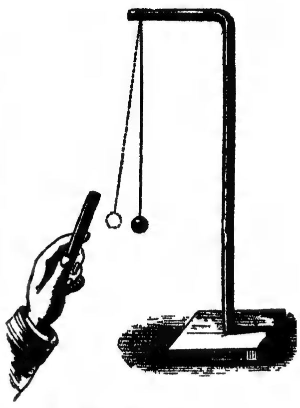


Fig 3.—Pith Ball Suspended to a Bent Glass Rod by a Piece of Silk.

When water holding salts in solution is in contact with the soil, electricity is always developed, the water becoming generally, though not always, positive, and the soil negative; the arrangement seeming to depend on the kind and quality of salts in solution. This last fact points to the origin of a thunder-storm; from this small beginning, which can scarcely be noticed even with the aid of the most delicate apparatus, arise such terrific storms as we have described. We know that from the surface of the sea and all water on the surface of the earth, there ascends into the atmosphere, especially in hot weather, a constant stream of invisible particles of water, which, on condensation by cold or other causes, form clouds. Now these particles of water carry up with them the still more invisible electricity they have acquired by contact with the earth.* Having discovered this feeble source of electricity, we shall proceed to investigate the laws by which it increases so much in energy as to produce the great effects we have observed. As we know electricity is produced in small quantity by rubbing a glass rod, we endeavour to increase the quantity or intensity on the same principle. Accordingly, we make a machine like that in Fig. 4. It is a glass cylinder (taking the place of the glass rod) mounted on brass bearings so that it can be

* Professor Tait has shown that friction between particles of watery vapour and the air develops electricity, and thinks this may be one of the sources of atmospheric electricity.

made to revolve; C is a cushion pressed firmly against the glass cylinder, and takes the place of the wax; B is called the *prime conductor*, and is a

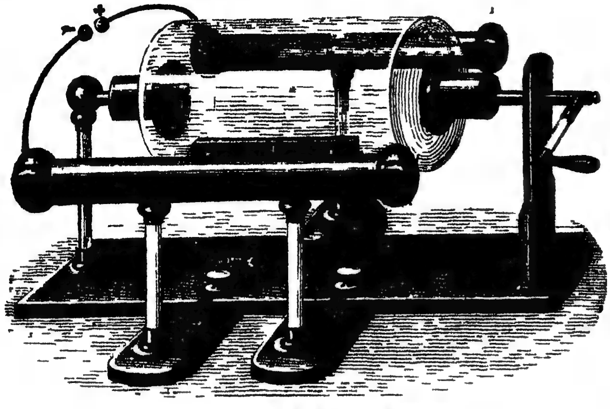


Fig 4.—Cylindrical Electric Machine.

metal cylinder, supported on a glass pillar, and having sharp points on the side next the cylinder, but not touching it. This takes off and accumulates the electricity developed by the rubbing of the glass. A piece of silk is placed on the top of the glass to prevent the electricity going off into the air.

When we turn the cylinder of this machine, and examine the prime conductor with our pith ball, we find it is charged with positive electricity, like glass.

With this machine we get clear indications of the power of electricity to produce light. While it is in operation, if we look into the space between the sharp points of the prime conductor and the revolving cylinder, we see sparks of light passing between them; or if we bring our finger within, say, half an inch of the body of the prime conductor, a bright spark passes between them, accompanied with a sharp snap, and we feel a sort of prick on the finger.

Putting our machine in motion, we shall make one or two experiments.

(1) Attach a small metallic chain to the prime conductor B, and let it hang down and touch the ground. If we look now at the sharp points of the prime conductor, we shall see the light still passing from the glass as it revolves; but we shall not be able to get any spark from the prime conductor itself, nor will the pith ball indicate that it is electrified. Now, clearly, the cause of this is that the chain is *conducting* all the electricity down to the earth as fast as it is produced. We therefore say the chain, or any body that acts like it, is a *conductor* of electricity; and as the electricity did not escape to the earth either by its glass support or through the air, but accumulated on the prime conductor, we say glass and air, or bodies that act like them, are *non-conductors* of electricity. We shall see that this observation is of great importance in understanding the "thunder-storm." Further, we notice that the air is not absolutely a non-conductor, for the electricity passes through it in the shape of a spark, but that to produce this spark of any size we must accumulate electricity so as to burst through, so to speak, the resistance of the non-conducting air.

(2) Place before the prime conductor of our machine a metallic cylinder supported on a glass pillar, as in Fig. 5. On charging the prime conductor as before, by causing the glass cylinder to revolve but not causing a spark to pass, we shall find that one end of the cylinder (A) next the prime conductor on being tested with the pith ball is charged with negative electricity, and the other end (B) with positive,

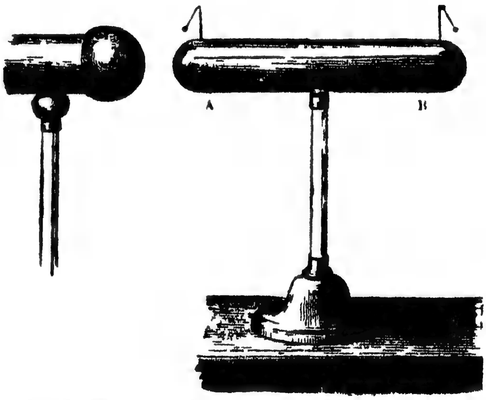



Fig 5.—Metallic Cylinder before the Prime Conductor.

marked in the figure — and +. On causing one spark to pass, the cylinder will return to its ordinary state, and exhibit no trace of electricity whatever until the machine is again set in motion.

(3) Let us repeat the foregoing experiment, with this alteration:—Attach a metallic chain to the cylinder, and let the end of it touch the ground. On charging the prime conductor again, we shall find on testing that the cylinder has negative electricity over its whole length, which will also disappear on the passage of the spark.

These three experiments show that electricity may be generated in another way than by friction or contact. As this has been brought about by the mere presence of an electrified body (the prime

conductor), it is called *induction*, because the one body has induced electricity in the other body near it. It has to be noticed also that positive electricity always induces and holds negative electricity nearest it, driving the positive as far away as possible, and holding the negative so firmly that although there is a conductor down to the ground it remains on the cylinder. Of course negative electricity induces positive. We see also that the passage of the spark reduces the whole arrangement to its natural state.

On the principle of induction we shall now construct an apparatus to enable us to increase the quantity of electricity before the spark passes. For this purpose we take a glass jar or bottle, about, say, ten inches high, and cover it inside and out to within two inches or so of the edge with tinfoil; we connect the tinfoil on the inside with a metal rod surmounted with a little ball which rises above the mouth of the jar about two inches. The arrangement is shown in Fig. 6. On connecting the brass ball with the prime conductor of our machine, and setting the latter in motion, positive electricity passes into the jar and accumulates on the tinfoil. It cannot pass to the earth, because the non-conducting glass jar prevents it; but it induces negative electricity on the tinfoil on the outside of the jar (which takes the place of the cylinder in our former experiment, being connected with the earth). By joining a number of these jars together by the little brass balls, we get that very powerful arrangement for accumulating electricity called an electric battery (Fig. 7), and when fully charged we can cause a spark of great brilliance and strength to pass, and the sound accompanying its passage is greatly augmented. With this apparatus we can imitate many of the phenomena of lightning, though of course on a much smaller scale. When one of these jars fully charged is held in one hand and the brass ball touched with the other, a violent shock is felt by the operator. A complete battery will give a shock sufficient to produce serious danger, so that it requires careful handling. With a very large battery blocks of wood can be rent in pieces, thin metal wire, gold-leaf, &c., can be melted or even dissipated in vapour. In fact, a miniature thunder-storm can be produced.


Fig. 6.—A Leyden Jar.

Having thus worked our way up from the elementary principles of the production of electricity by friction, contact, and induction, to the production of phenomena similar to those displayed in a thunder-storm, we are in a position to trace out and explain the whole process. We learn that a thunder-storm is only the climax of unseen action that has been going on for some time; the little particles of water have been silently carrying upwards their little loads of electricity acquired by contact with the earth; as they increased in size by uniting in the form of clouds, the electricity increased in intensity from the same cause, so that the cloud becomes like the inside of the electric battery, highly charged by an electric machine. Then the air acts like the glass of the *jar*, and the earth like the tinfoil on the outside, and consequently by induction gets strongly charged with negative electricity as far as the influence of the cloud extends. As positive and negative electricity mutually attract, and the cloud is movable, the latter approaches the earth. When any part of it gets sufficiently near for the electricity to burst through the intervening non-conducting air, a flash of light passes. The foregoing is in general outline an account of what goes on during a thunder-storm.

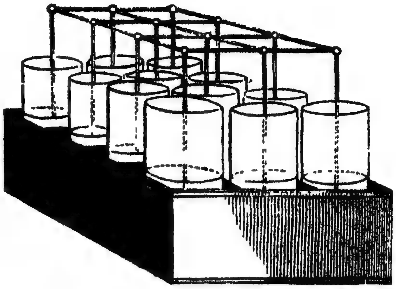


Fig. 7.—An Electric Battery.

We shall now endeavour to explain some of the facts we noticed while the storm was raging, on the principles we have worked out.

(1) The uncertain movements of the smaller clouds. As stated before, water in contact with the earth is not always charged with positive electricity; it is sometimes negative; consequently we may have clouds variously charged, and there will be attraction or repulsion between them, according as a positive cloud meets a negative cloud or another positive one.

(2) The flashes of lightning in the body of the

cloud itself are accounted for on the same principle. Parts of the cloud separated by some little distance and differently charged flash a spark between them as they approach. If this occurs on the side of the cloud furthest from us, we may not see the lightning clearly defined, but only as a flash lighting up the whole surface; or if the cloud is dense enough, we may see only the edge illuminated brilliantly, although no electricity is passing from them.

(3) The powerfully destructive effects of lightning are seen from our experiments to be due to the electricity bursting through a bad conductor, such as stone, wood, bricks, or even the human body. We never see any of these effects when electricity is passed through a good conductor like a metal chain, if it is of sufficient size.

(4) The cause of lightning varying in form, being sometimes a zig-zag line and sometimes forked, is supposed to be due to the intensity of the charge driving as it were the air before it, and consequently condensing it more or less; and the lightning seeks out the path of least resistance. At any rate, we can imitate these forms with our battery, and find that as the length and intensity of the spark varies, its form also varies.

It has been shown, however, by some very cleverly executed photographs of the electric spark, that when every trace of floating particles is removed from the air, the spark is always straight, so that the different forms of lightning may be due to the electricity darting from particle to particle that floats in the air. The globular form is not well understood, but we know that the greater or less density of the air, and the charge, exercise much influence on the form and also on the colour of the spark.

(5) We observed that when a flash passed from the thunder-cloud to the earth there was a return flash at some distance, which might be traced all through the cloud. To explain this, we must remember that when a flash takes place the action is not confined to the precise spot where it occurs. The whole thunder-cloud, the air between it and the earth, as well as the earth itself, are in a condition of strain; the positive electricity of the cloud is holding a like quantity or equivalent of negative on the surface of the earth near it, and every object on that surface is more or less under this strain. When the spark passes, this strain is relieved for the moment, and there is a general rush back, so to speak, of the electricities to their natural condition; and this rush back is of sufficient intensity to cause a second flash at a distance, besides sometimes causing a severe shock to men or animals subject to its influence. We may form, perhaps, a more definite idea of this state of strain by considering the following mechanical arrangement. Let us take a tubular glass ring, one side of which is of less diameter than the other, as in Fig. 7; fill its under part (M) with mercury, and the upper (W) with water, and let the surfaces where the water and mercury meet be represented by the lines P and $P_1$. If we now by means of a piston at P press down the level of the mercury to $P_2$, the whole body of the mercury will be moved, and it will rise on the other side from $P_1$ to $P_3$, but its movement will be greatest where the tube is narrowest, and least where it is widest. In this position, the mercury will be in a position of strain maintained by the pressure of the piston; on removing the piston there will be an immediate return to its first position, and the whole body of the mercury and water will partake of the movement in proportion to the diameter of the tube at each part. Now this represents the state of matters before a flash of lightning passes between the cloud and earth. The narrowest part of the tube represents the point where the electric intensity is greatest, and the widest part where it is least. The passing of the spark represents the withdrawing of the piston, and the return movement of the mercury and water the recombining of the electricities into their natural state, causing shock or spark varying in intensity.

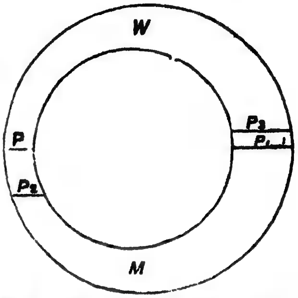


Fig. 8.—Illustrating the Passage of a Flash of Lightning between a Cloud and the Earth.

During our thunder-storm, we noticed that buildings having a rod of metal descending from their highest point into the earth, called "lightning-conductors," were not injured by the storm. Can we explain the reason of this? We have seen by our experiments that electricity passes away from a conductor if it is connected by a metal chain with the earth, but not if it is connected by glass. Let us now work our machine (Fig. 4) till we get a spark when we bring our finger near it. If we now take a metal rod in our hand, and hold it close to our finger, so that its end coincides with the point of the finger, and bring both near the prime conductor of our machine, we shall find we cannot now get a spark to touch the finger; it will invariably pass to the metal rod, and if the rod be long enough to

reach the ground, the electricity will not pass through our body at all, but pass straight to the earth by the metal rod. If, however, instead of a metal rod we take a glass one, and use it in the same way, the result will be very different. Now we shall not be able to get a spark to touch the glass at all; it will invariably strike the finger, and pass through our body to the ground. If, therefore, we have a metal rod standing fixed in the ground beside us during a thunder-storm, a flash of lightning coming would, like the spark from the conductor, pick out the metal rod and pass by it harmlessly to the ground, leaving us untouched. On the other hand, were a glass rod beside us, the lightning would leave the glass rod untouched, and pass through our bodies to the ground, most likely depriving us of life in its passage. This is the whole principle of lightning-conductors. We express it by saying that electricity always passes by the best conductors. To act efficiently, however, the lightning-conductor should be sharply pointed, as it then draws off electricity so rapidly from the clouds that the intensity can never rise sufficiently to cause a spark or flash. It is found by experience that a rod erected in this way protects a space all round it equal to twice its height. Thus a rod 50 feet high protects a space of 100 feet on every side of it. From the knowledge of the principles of lightning-conductors, we may know the positions of safety. The French *paragrêles* are also other forms of lightning-rods. They are small conductors, set up by means of poles in the vineyards in France, to draw off the electricity from

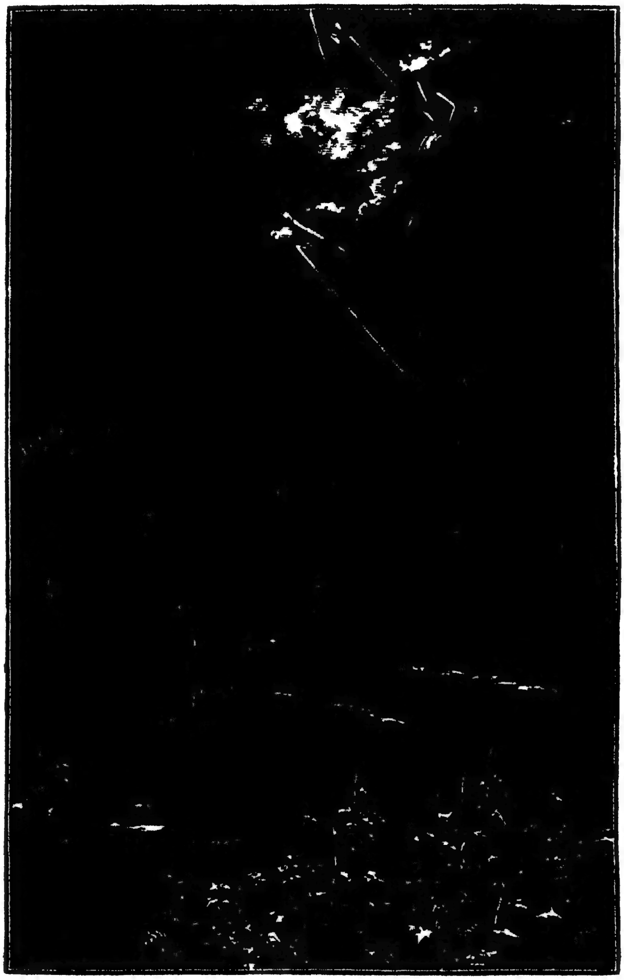


Fig. 8.—Arago's Paragrêles

the atmosphere over them, and thus prevent the accumulations which, when they occurred, were found to generate hailstorms. Arago proposed that these conductors should be raised and supported by small batteries, connected by means of slender wires or chains with the ground. This plan, like some other ingenious applications of electricity, was found to act perfectly well in theory, but proved impracticable, owing to the great expense of setting up and maintaining such a system over any great extent of country.

Cases have been known in which a gold pin in a girl's hair has been fused by lightning, or a bracelet melted off a lady's wrist, without the wearers suffering any actual injury. Sportsmen, owing to the iron of their weapons, are apt to be struck by lightning. Hence, some philosopher—half in jest, half in earnest—has proposed that a portable lightning-rod in connection with an umbrella should be provided for people liable to be caught in thunderstorms. Such a *parapluie*, if the ferrule were provided with a pointed metallic rod projecting into the air, and connected with a detachable chain or wire to drag on the ground behind, could bring the bearer and his paraphernalia of destruction safely through the electric tempest, even though the lightning should play all around him. We must keep away from the neighbourhood of bad or non-conductors, and near to good ones, if they are connected with the ground. A man clad in the steel armour of the Middle Ages would be almost perfectly safe, especially if he had steel points on his boots to stick into the ground, as he would have a capital conductor all round him. For the same reason, a man in an iron bed will be safe, especially if the bed be connected by metal to the gas-pipe, so as to make complete contact with the earth. Standing near a high body like a tree is dangerous, because electricity always rushes to the highest points; and unless the body is a better conductor than a man or woman, the electricity will strike out towards the man or woman.

We have lastly to notice the thunder. It is, of course, just the snap we hear from our electric machine greatly intensified, and is no doubt caused by the violent commotion in the air by the rush of electricity through it. As light travels enormously faster than sound, we see the flash before we hear the sound, the interval depending on the distance of the lightning. As sound travels in air about 1,120 feet in a second, we can always know the distance in feet by counting the number of seconds that elapse between the flash and the thunder, and multiplying by 1,120. The various kinds of thunder are supposed to be caused by the varying distances from which the sound comes.

Hitherto we have made no attempt to explain the nature of this wonderful agent electricity. We have rigorously confined our attention to facts, and the plainest inferences from them. The reason of our doing so is just this: we are in absolute ignorance of what electricity really is. Some suppose it to be a fluid, and others a mixture of two fluids, and it may be neither. Until, therefore, something more definite is known, it is better for us to refrain altogether from theory, and to be very careful to avoid the use of expressions which are apt to mislead, and which may impart not knowledge, but fancies, which have to be unlearnt again as science advances.

## THE CHEMISTRY OF A PLAIN BREAKFAST.

By Professor F. R. Eaton Lowe.

WHILE we are sitting down to breakfast, with no more luxurious accompaniment to our bread and butter than a cup of coffee and an egg or two, we may profitably throw aside for once the morning paper, and endeavour to collect a few facts respecting the nature of what we are consuming, and what part it is likely to play when it is consumed. It is much to be regretted that, in these days of scientific research, when scientific men meet with more appreciative audiences than ever, and scientific books enjoy a wider circulation—when science, in short, is, to speak colloquially, "looking up"—there is as much general ignorance respecting the constituents of food and the composition of the human body, which has to be built up and kept in repair through the instrumentality of that food, as there was fifty years ago. We still select our food, as we have done time out of memory, from considerations of taste, without any reference to its nutritive value; and a dish that does not contain a grain of albumen or other flesh-forming material, is eaten with as much avidity,

provided it please the palate, as if its composition admirably fitted it to enable the body to perform its functions with unimpaired vigour and regularity.

There is no doubt that a goodly proportion of the "thousand ills that flesh is heir to" might successfully be guarded against by a wider dispersion amongst us of physiological knowledge, and a more general acquaintance with the chemistry of the human body so far as it relates to the appropriation and assimilation of food. How is it that the average duration of life is little more than half the orthodox threescore years and ten? Look around, and mark the general neglect of sanitary laws, and the answer is plain. Impure air, intemperance, and dissipation produce a long catalogue of disorders; but errors in diet are as effectual in shortening life as any of these causes, and are, perhaps, of more common occurrence. Intemperance and dissipation are not gentlemanly vices, but errors in diet are highly respectable, and sanctioned by the usages of the most fashionable society. Rich soups, highly-seasoned dishes, and hot condiments are swallowed in defiance of the simplest dietetic laws, while the poor stomach, constructed for simple fare in moderate quantities, is distended with a huge conglomerate of fish, fowl, flesh, and pastry which the gastric juice cannot permeate, and the digestion of which can only be effected by a disastrous expenditure of vital force. In youth and early manhood the elasticity of our constitution is such that a considerable amount of abuse can be borne without much apparent injury or loss of tone; but sooner or later there will come a revolution: the ill-used organs will rebel, and terrible will be the revenge they will take for the long-continued slavery and hardship to which they have been subjected.

Very little reasoning is required to show that there ought to be a close chemical relationship between the food eaten and the tissues which it is designed to build up. Every moment of our lives, disintegration, or the breaking up of minute fragments of the tissues, is taking place. Every organ, every vessel, and every muscle is perpetually losing part of its substance by the exercise of its own function. Even the brain is worn by every act of thought; and the effete or worn-out particles are carried away by the lungs, the skin, and the secretions. In order that renovation may go on side by side with disintegration, we eat, and unless our food be of the proper description, and in proper quantity, the rate of wasting will be more rapid than that of repair, and emaciation will result. In our article on "Milk" (p. 138) it was stated that food might be divided into two classes—flesh-formers and heat-givers, the former being nitrogenous, and the latter containing excess of carbon and hydrogen. We here give the proximate principles comprised in these two classes, in the form of a table:—

| | |
|---|---|
| 1. Heat-givers . . | Starch (Amylose).<br>Sugar (Sucrose).<br>Oleaginous substances (fat, oil). |
| 2. Flesh-formers . | Albumen.<br>Fibrin.<br>Casein. |

The heat-givers are respiratory—that is, they promote the function of respiration by their excess of carbon. This element combines with the oxygen of the air in the lung-cells, and in so doing gives out that heat which preserves the temperature of the body at 98° in all latitudes. We proceed to speak of each of the above organic elements in detail.

And first let us say something of *starch*. The importance of this vegetable principle will be understood from the fact that it enters more largely than any other into the composition of the food of all races. Those who make bread what it ought to be, and what it was designed by nature to be—that is, the real *staff* of life—take more starch than any other organic vegetable compound. It forms three-fourths of the weight of fine wheaten flour, and exists in still greater abundance in sago, arrowroot, tapioca, semolina, and cassava. Cereals seem to have been selected by man from the beginning of his history as his chief source of nourishment. All over the world, even amongst the most barbarous nations of Africa, we find grain of some kind cultivated for the purpose of bread-making. From the region of rye and barley, extending to 70° north latitude, down to that of rice and maize within the torrid zone, we find the cereal grains instinctively regarded as constituting the great life-sustainer of the masses; while meat is simply an auxiliary, and in most countries a luxury obtainable only by the rich. The bulk of this important article of diet, then, is starch; an element which is equally prominent in seeds and fruits generally, as peas, beans, nuts of all kinds, apples, pears, and especially in those fruits, such as cassava, banana, and bread-fruit, which take the place of wheaten bread in countries of which they are natives. As starch is placed in the same sub-division of food constituents as fat, it must exert a similar physiological action.

Starch is not a flesh-former, and therefore the reader may be disposed to infer that the value

placed upon grain, which contains so much of it, is rather theoretical than substantial. It has already been stated that we require something besides the mere muscle-building elements to sustain all our functions; and it must be further laid down, that

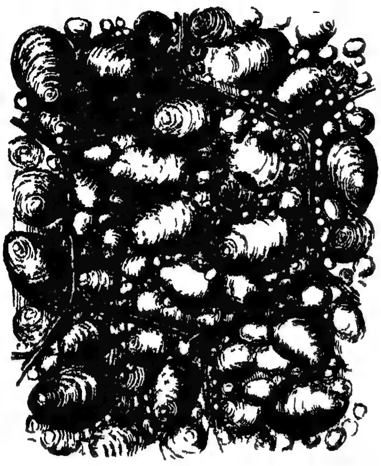


Fig 1.—Granules of Potato Starch (*Magnified.*)

*bulk* is another consideration of some importance in the selection of our food. The most nutritious substances in a highly concentrated form, and consequently in small bulk, used as food for a lengthened period, would fail to be attended with those beneficial results which might be anticipated

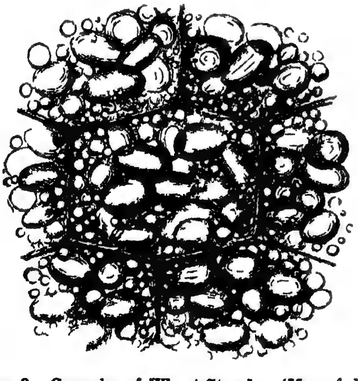


Fig. 2.—Granules of Wheat Starch. (*Magnified.*)

from their chemical composition. To attempt to live altogether on extract of beef would be as hazardous as to endeavour to satisfy our thirst by taking our beverages boiled down to one-tenth of their original volume. To satisfy his appetite, a Hindoo must devour several pounds of rice daily; and an English farm-labourer will eat an amount of bread with his cheese and onion that would astonish an exquisite, who has simply heard of the "staff of life," but does not altogether see the logic of the phrase.

The amount of starch found in various vegetable articles of food varies from $2\frac{1}{2}$ oz. to the pound of

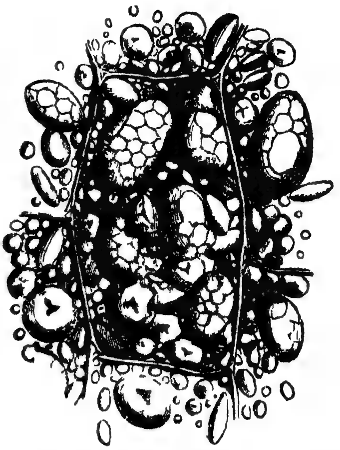


Fig 3.—Granules of Maize Starch. (*Magnified.*)

potatoes, to 12 oz. in the same amount of rice. Leaving out the potato, the nutritive value of these products may be taken in inverse ratio to the proportion of starch they contain. Thus, peas contain more flesh-forming material than barley, and barley more than wheat, while rice is the least nutritious of the cereals. The studious housewife who peruses this article may say that she always looked upon rice puddings as very wholesome "things." To

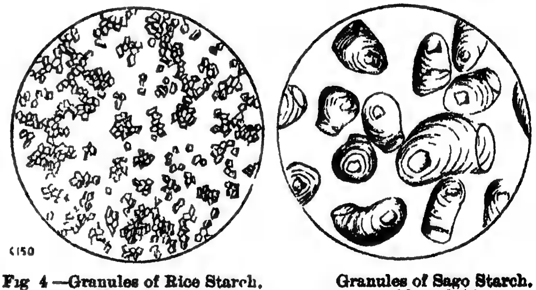


Fig 4.—Granules of Rice Starch. (*Magnified.*) Granules of Sago Starch. (*Magnified.*)

which we can only reply that so they are; but if you gave your children nothing but rice, they would require half a dozen such puddings a day, with a plentiful admixture of milk and eggs, if you wished them to have straight limbs and strong frames.

Pure starch may be obtained from flour by a very simple process. Tie up a table-spoonful of wheaten flour in a muslin bag, and repeatedly press it with

the fingers in a basin of water. The water will be rendered milky, owing to the separation of starch. Continue the process till a fresh portion of water is no longer rendered turbid, and after subsidence the water can be poured off, and the starch dried and preserved. After the experiment with the flour, a glutinous, adhesive substance will be found in the muslin bag. This is *gluten*, the real flesh-forming element which gives bread its true value.

Fig 5 —Subterranean Branches or Tubers of Potato.

The conversion of starch into sugar is a process very extensively carried on by nature, both in the vegetable and animal kingdoms. In every germinating seed this chemical change is going on: every ripening fruit is developing its sugar at the expense of the starch; and every sweet root, tuber, or esculent owes its excellence to the same transformation. The carrot, turnip, parsnip, and beet-root, when very young, present no symptom of sweetness, while immature fruits are intensely sour; but as the sun's heat increases, those changes are set up in the ascending and descending sap which result in the formation of sugar. In some cases, nearly the whole of the starch is converted, as in the sugar-cane, the stalks of maize, manna from the ash, and in over-ripe grapes and dates; while in liquorice-root, beet-root, sweet potato, the milk of the cocoa-nut, the milk of the cow-tree (*Palo de vaca*), and many other vegetable products, enough sugar is developed to give them a sweetish taste.

Starch is insoluble in cold water, but dissolves in hot water, forming a gelatinous solution, by the breaking up of the little starch-granules, which, under the microscope, are seen to differ in size and shape according to the source whence they are derived. The microscope is the only means by which one species of starch can be distinguished from another; and thus becomes an important instrument in the hands of the analyst for the detection of food adulteration. The granules of potato-starch are much larger than those of the cereal grains (Figs. 1 — 4), and are elongated,

resembling somewhat a mussel-shell in outline. The transformation of starch into sugar is a phenomenon equally common in the animal kingdom. It takes place in our own bodies, whenever the process of digestion is proceeding. The metamorphosis is commenced by the saliva, and such is its energy, that sugar has been detected in starch that has been in contact with the saliva for fifteen seconds only. This fact furnishes a cogent reason for the due mastication of our food.

We next come to sugar. This substance is so generally distributed in nature, both in plants and their fruits, and in the bodies of animals, that considerable importance must be attached to it as an article of diet. It is found in the liver and muscles, in milk and other secretions, in the sap of trees, in flowers as nectar, in grain, and in every species of edible fruit: in short, there is hardly a dish served up to table, whether derived from the animal or vegetable kingdom, that does not contain more or less of it naturally, though it may be in a disguised and unrecognisable form. There are several varieties of sugar, differing from one another in solubility, sweetness, and crystallisation, such as cane-sugar, grape-sugar, fruit-sugar, milk-sugar, &c. The one which we are most familiar with is cane-sugar,* obtained principally from the stems of the sugar-cane (*Saccharum officinarum*), but frequently prepared from the stalks of maize or Indian corn. One gallon of the juice of the former yields about one pound of sugar. The canes are crushed in a mill, and the juice boiled with lime, which causes the gum and other extraneous matters to rise to the surface as a frothy scum, which is constantly removed till the liquor becomes clear. It is then boiled and concentrated in copper pans, filtered through linen bags to separate pieces of cane and woody fibre, and set aside to crystallise. The produce has a dark colour, and constitutes the raw or brown sugar of commerce. The uncrystallisable portion drains away, and is known as molasses or treacle. White or refined sugar is made from the common raw sugar, by boiling and filtering through bone-black or animal charcoal, which possesses remarkable decolorising properties. Bullock's-blood is then added, the albumen of which coagulates by heat, like the white of an egg. During coagulation, it combines with the remaining impurities, which are then easily removed, on the same principle as that involved in certain clarifying operations often performed in the kitchen. The decolorisation being complete, and the liquor perfectly pellucid, it is boiled down to the crystallising point in "vacuum pans," at a temperature of 150° instead of 230°, which would be necessary in open pans. By this means, charring and consequent discoloration, which often occurred under the old system, are prevented, and whiter and finer crystals are produced. It is allowed to crystallise in conical moulds, and a further portion of uncrystallisable syrup drains through a hole in the apex. This is sold by grocers as syrup treacle, or golden syrup.

When allowed to evaporate spontaneously, sugar produces large prismatic crystals, familiar to our young people as sugar-candy; and when the syrup is saturated to excess, and cooled, it concretes into an amorphous mass equally familiar as barley-sugar. The amount of sugar contained in different vegetables varies from 2 per cent. in peas, 3 per cent. in turnips, 6 per cent. in carrots, to 45 per cent. in the beet-root.

As an article of diet, sugar holds a very important place. Its universal distribution may be taken as strong evidence of its utility; and the experiments of physiologists, as well as the instincts of mankind generally, point to the fact that its action on the human system is as salutary as its taste is delightful. There seems to be a natural craving, especially amongst children, for this substance, and this alone is an indication which is sufficiently significant.

Dr. Edward Smith, from a series of elaborate experiments, found that sugar facilitated the function of respiration by increasing the exhalation of carbonic acid; if this be true, persons somewhat advanced in years may advantageously "go shares" in the brandy-balls and "bulls'-eyes" which afford so much solace to their grandchildren under the heaviest trials.

But we must modify this statement by a word of warning. At those establishments where sweetmeats are sold, there is usually a display of colour as gorgeous as the prismatic spectrum itself. But be not tempted thereby. Avoid those beautiful green drops, those gaudy yellow sticks, and those pretty red tablets, for there is poison within. But, the reader may ask, "Do you mean to tell us that there is any danger in eating those familiar sweets? I never heard of such a thing!" Well, it is time you did, for if you regale yourself on "Scheele's green" (arsenite of copper), or "chrome yellow" (chromate of lead), or red lead (oxide of lead), or "vermilion" (mercuric sulphide), all of which have been detected in sweets, you must take the consequences, which

* Which in formula is written $C_{12}H_{22}O_{11}$—that is to say, it contains 12 atoms of carbon, 22 of hydrogen, and 11 of oxygen.

will certainly not be trivial. Be faithful to your sugar-candy and barley-sugar, or acid drops, or any uncoloured confectionery not having the appearance and solidity of chalk or plaster of Paris—which is a very common source of adulteration—and no danger can accrue.

Like all other innocuous substances, sugar may be abused—or, rather, we may abuse ourselves by the intemperate use of it.

The fiction that pure sugar rots the teeth need not deter us from its use; there are no grounds, chemical or physiological, for entertaining such a notion. Any kind of matter of an adhesive nature, if not washed off, will promote decay of the teeth, and therefore sugar, in this respect, is no worse than pastry, puddings, or oleaginous foods.

The other sugars need not occupy our attention long. Grape-sugar or glucose* is that found in grapes, dates, figs, and other fruits, and also in the blood, and white of eggs. It is commonly used by confectioners, as it can be prepared cheaply. Lactose is milk-sugar, and as it forms about 5 per cent. of milk, is largely prepared in Switzerland, Vol. I., p. 139.

Now let us turn to the oleaginous substances. Fat and oil are compounds of considerable physiological interest and importance. "All skin and bone" is a condition of things notoriously uncomfortable, but such physical condition would speedily be brought about by eliminating from our diet every form of oleaginous matter. There are few parts of the body in which fat ought not to be found, if nutrition has been properly effected. Besides layers of fat between the muscles—or flesh—and the different internal organs, and the superficial layers, which by their excess give rise to corpulence, there should be fat in the substance of the muscles themselves; it is present in the brain, it lubricates the joints, exudes through the pores of the skin in the form of perspiration from the oil-glands beneath, and finally, it can be expressed from the liver, heart, and other organs of the body.

It is no less common in the vegetable world. In the solid or liquid form it is found in nearly all seeds and fruits. The value of these fatty substances as heat-givers is practically and instinctively tested by the inhabitants of all cold countries, whose coasts the Great Whale and other animals of the order *Cetacea* seem to haunt in such abundance as if for the special purpose of supplying the necessary oleaginous aliment.

* Chemically, $C_6H_{12}O_6$.

A Greenlander would regard a meal of whale-blubber as a dainty feast, and a quarter of a seal as only a sufficiency; while a Russian of the northern provinces can manage to dispose of ten and twelve pounds of fish or meat daily, without any uncomfortable strain on his digestive organs. This is intelligible only on the chemical theory already explained. In Arctic countries, we must remember that the temperature is often as low as 40° below the zero of Fahrenheit, while that of the human body must be maintained at 98°. This gives us a range of 138°, and the necessity for increasing the activity of the respiratory function at once becomes apparent. This is effected by an increased consumption of carbon, which, by its union with oxygen within the body, causes the evolution of heat. Now, in 100 lb. of fat there are 77 lb. of carbon, so that the Greenlander's *penchant* for blubber is not the result of gluttony, but instinct. Still, there are luxuries which even an Eskimo can appreciate. A tallow candle, for instance, is a delicacy which does not often come in his way; but it is well known to Arctic navigators that the ship's stock of "dips" often mysteriously disappears when the Hyperboreans are permitted on board.

Fats are composed principally of two elements, *stearine* and *oleine*, the former being most abundant in solid fats, and the latter in oils. If mutton suet is pressed between several folds of blotting-paper, the oleine is absorbed, and the stearine remains as a white mass, harder and more translucent than the original suet. A pound of mutton suet contains about three-quarters of a pound of stearine, while the same weight of olive oil contains but one quarter of a pound.

A few words are now due to *Albumen*. This is the most important of the flesh-forming elements, and is that part of our food upon which nutrition mainly depends; for take away the albumen and the *gluten*, which is probably the same substance in another form, and starvation must speedily follow, no matter how liberally we may partake of starch, sugar, and fat. Albumen is found in almost every fluid of the body except the bile. It is an essential part of the blood, and an important constituent of the brain, the spinal cord, and all the nerves emanating from it. It is present in the humours and crystalline lens of the eye; in the glands or secreting organs, as the liver and kidneys; in the *synovia*, which lubricates the joints and hinges of the machine, &c. In the white of egg we have albumen in a tolerably pure state, and we are all familiar with the property which that viscid

fluid has of coagulation, or of becoming solid by the application of heat, when it loses its transparency and becomes opaque and yellowish-white. The value of albumen in a dietetic point of view will be fully appreciated when we call to mind the extraordinary metamorphosis it undergoes in the hatching of an egg. From the albumen alone the whole bird, step by step, is built up and developed. The bones in their gelatinous state, the muscles, the blood, the feathers, beak, and claws are all produced at the expense of the albumen by the action of some hidden and marvellous vital force upon its chemical elements. An egg, then, is a highly desirable accompaniment to our breakfast. If you can eat two, by all means have them; you will thereby secure more available nutriment than can be derived from seven or eight ounces of cooked meat. Take care that they are fresh, or not more than twelve days old in cold weather, and that they are boiled for three and a half or four minutes only. Albumen is composed of the four elements, carbon, oxygen, hydrogen, and nitrogen, in addition to two per cent. of sulphur. When we use a silver spoon, it is blackened; this is owing to the formation of silver sulphide, or the chemical union of the sulphur of the egg with the silver of the spoon.

*Fibrin* is the nutritive element in meat and fish, and resembles albumen in composition. As we have not so much as a rasher of bacon for our breakfast, we shall not dwell upon this substance, but go on to speak of an important modification of it called gluten, to which seeds and grains owe their nutritive value. It is the substance left in the muslin bag in the experiment for the separation of starch already described. It is viscid and tenacious, resembling glue, and cannot be long kept without undergoing decomposition. The claim of bread to be considered the "staff of life" depends upon the presence of gluten; and the comparative nutritive power of the cereals may be best estimated by ascertaining the relative proportions taken up by this substance. It varies in different breadstuffs from $2\frac{3}{4}$ oz. per pound in oats to a quarter of an ounce in a pound of potatoes.

*Casein* is the flesh-forming element in cheese, which, as we are neither Essex farmers nor Dutch Boers, does not appear on our breakfast-table; we therefore leave it out of consideration for the present, and come to

*Bread.*—The method of making bread is too well known to require description; but it is not so generally known that the action of the ferment known as yeast is to transform a portion of the starch into sugar, and ultimately into carbonic-acid gas and water, with a trace of alcohol. The baker, however, does not care about the alcohol, or the water, or the sugar; his sole object is to secure the services of the carbonic-acid gas (carbonic dioxide), which, in endeavouring to escape from the heated mass, distends it, and imparts to it that spongy character without which bread would be unfit for daily use. Without the employment of this gas to give the necessary porosity, the loaves would be turned out in the condition of pudding. Something approaching this condition is seen in bread that is "slack-baked," which is heavy, either from too much water having been used in the mixing, or from the employment of insufficient yeast to develop the required volume of gas. Any method by which carbonic acid may be generated within the dough can be adopted in bread-making. Thus, if we mix the flour with bicarbonate of soda, and knead it with water containing tartaric acid, decomposition of the salt will take place. Carbonic acid will be evolved, and tartrate of soda left in the bread. This method is often adopted in making buns and light cakes. A third method is that followed in making the now well-known aërated bread, and which was first suggested by Dr. Dauglish. By this method the flour is mixed with aërated water. Under pressure, water can be made to absorb six or seven times its own volume of carbonic acid, the whole of which it gives off again on heating. The flour is well mixed with the charged water in a strong vessel by means of revolving levers, and then rapidly transferred to the baking-tins by ingenious machinery, so that all handling is rendered unnecessary. When the tins are placed in the oven, the heat at once acts on the contained gas, which escapes, and gives the required lightness and porosity to the loaves. This method has many advantages. There is no loss of starch, there are no products of decomposition left in the bread, and the fingers (not to say feet) of the workmen are kept clear of the sponge. It has also the merit of expedition, the whole process occupying but half an hour. It is not likely, however, to supersede fermented bread altogether, as its taste is less sweet, and it rapidly becomes dry and hard.

The brown crust on the upper surface of the loaves is an effect of the heat radiated from the roof of the oven. It is viscid or gummy, especially if it has been moistened with water while hot, because starch is converted into a kind of gum

by roasting. Those with whom brown bread agrees should use it in preference, as the bran with which the flour is mixed is rich in gluten, chiefly found on the outside of the grain, or in that portion which the miller removes by his grindstone; in very white bread, on the other hand, the flour by repeated sifting has been deprived of much nutritive matter, and the proportion of starch consequently becomes excessive. The popular prepossession in favour of very white bread offers an incentive to bakers to adulterate their flour with alum, the alumina of which combines with the phosphoric acid of the partially decomposed gluten, and forms aluminium phosphate. Alum is an astringent, and therefore cannot be taken in an article that we are using every day, such as bread, without giving rise ultimately to injurious consequences. The bitter taste that it imparts to bread, when employed in large quantities, is sufficiently indicative of its presence and is easily noticed. It may also be detected by the logwood test. Infusion of logwood assumes a purple hue in presence of alum.

Lastly, never eat new bread. Let it be kept twenty-four hours, covered up in a cool place, before it is brought to table. The general adoption of this precept would put an end to the hot French roll business; but man was not made for the baker alone. Bread brings us to

*Butter.*—Butter is a fat, and therefore its chemistry and physiological effects are the same as those of oily substances generally. As bread is deficient in fat, the use of butter as an accompaniment to our slice of bread is thoroughly rational. To be beneficial, it must be pure. There is probably more bad butter in the market than bad bread. The cheap sorts are often adulterated with lard, or even tallow derived from the most inferior kinds of mutton fat; while the suspicious whiteness of the mixture is covered by *annotto*, a colouring matter derived from the pulpy seeds of *Bixa orellana*, of Central and South America, and often used to heighten the colour of Cheshire cheese. The execrable compound of butter and tallow sold at a shilling, or even as low as tenpence a pound, need not deceive anybody who possesses the sense of taste in its integrity. There is simply no taste of butter in it, but a flavour so vile, that it is difficult to understand how any person can be induced to buy it. A more innocent source of adulteration is water, which is added to increase the weight. Six or seven per cent. of water is the natural proportion of this element in butter, but as much as 18 per cent. is often to be found, and can be removed by pressure. On weighing the loss can be readily ascertained. Our constitutions do not suffer much by this method of adulteration; but it is certainly not pleasant to be made to pay eighteenpence a pound for what we can get out of the tap for nothing. Finally, we come to consider the science of the

*Coffee*, which we have already made the gastronomic acquaintance of. The coffee-shrub (*Coffæa Arabica*) (Fig. 6) is a native of Abyssinia, the

Fig. 6.—Branch of the Coffee-tree.

name being a corruption of Caffa, one of the provinces of that country. From Abyssinia the plant was introduced into Arabia by the Arabs, and thence spread all over the world. The fruit resembles a cherry, and is at first red, but ultimately turns black. It contains two seeds, having their flat sides in contact, and surrounded by a tough integument or skin. The pulp is removed by maceration in water, and the seeds with their covering attached are then dried. The integument is removed by the action of rollers, so arranged as not to crush the seeds. The quality of the berries depends in a great measure on the geographical situation of the plantations. Those situated on hilly districts yield a finer product than those in the plains below. There is a difference in the colour of the beans

brought from Mocha, Bourbon, and Ceylon. The first have a greenish-yellow tinge, the second pale yellow, and the last a deeper yellow. Much of the flavour of coffee depends upon the roasting, which is therefore a process of considerable importance. If over-roasted, the aroma is destroyed, so that beans having a black or charred appearance ought to be rejected. The roasting is conducted in a cylinder, made to revolve slowly, so that the contents are uniformly heated. The proverbial excellence of French coffee is probably due to the care and judgment brought to bear upon the roasting, rather than to any peculiar method of preparing the beverage. The active principle which gives coffee its most characteristic property is a poisonous alkaloid called *caffeine*. It can be obtained in

Fig 7 —The Chicory Plant in Flower.

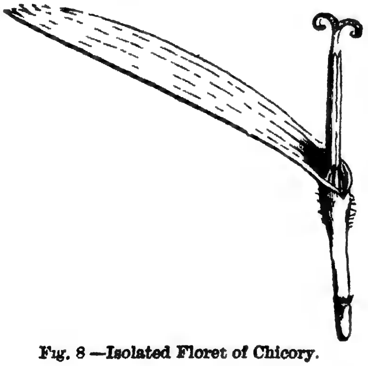


Fig. 8 —Isolated Floret of Chicory.

beautiful silky crystals, and, strange to say, is identical with the *theine* of tea, in which, however, there is one per cent. more of the alkaloid than in coffee. On this account tea exerts a more prejudicial influence on the nervous system than coffee; on the other hand, coffee dries the skin, while tea moistens it by promoting evaporation. Coffee quickens the heart's action, and checks sleep; so that unless the reader happens to be a student cramming for the "little go" by the midnight lamp, or a newspaper editor, whose "copy" is yet in his brain, or a policeman on night duty, he should not indulge in a strong decoction of coffee for supper. The practice of taking tea and coffee at high temperature is itself injurious, independently of the effects arising from the caffeine. It weakens the tone of the stomach by impairing its elasticity and contractility. Coffee should be used freshly ground, because the powder not only loses its aroma by keeping, but, like bone-black, absorbs many times its own bulk of gaseous matters or vapours which may happen to be floating within reach.

Coffee is most commonly adulterated with *chicory* (*Cichorium Intybus*), a plant resembling a dandelion, but with blue instead of yellow flowers (Figs. 7—8), and largely cultivated throughout Central Europe. The root is ground and roasted, and is then almost undistinguishable from ground coffee, to which, however, in chemical properties, it is totally dissimilar. The aroma of coffee is altogether wanting; it contains no caffeine or tannic acid, and is mainly starch, gluten, and woody fibre or cellulose. Mixed with coffee, it darkens the colour of the beverage; and its use is further justified by many persons on the ground that it gives "body" to the infusion. What is meant by this "body" is not particularly clear, unless it means a coarse and acrid flavour which disguises the natural bouquet of the coffee. To speak of the improvement of coffee by chicory is to use a figure of speech analogous to the hypothetical improvement of the lily by a coat of paint. Physiologically, chicory is more harmless than coffee, and its use is attended with less cerebral and nervous disturbance; but that is no reason why we should submit to have an article of such inferior value palmed off upon us as genuine Mocha.

But we perceive that our coffee-pot is empty, and the stock of bread and butter exhausted: our simple breakfast is therefore at an end.

# SOMETHING ABOUT GASES.

By T. C. Hepworth.

MATTER is presented to us in three different forms—solid, liquid, and gaseous. The ancient philosophers argued therefrom that there were in the universe but four simple bodies or elements—earth representing the solid, water the liquid, and air and fire the gaseous. Of these four elements they imagined every substance to be constituted. Matter, supposed to be only of one kind, was in some way governed by these elementary bodies, and in consequence appeared under different aspects; it seemed, therefore, no impossible task to our forefathers to change the nature of one substance into that of another, and many lives and fortunes were spent in the vain endeavour to find out that "philosopher's stone" which was to transmute the baser metals into the coveted gold.

But the labours of these dreamers were not altogether wasted, for the old alchemists, in their search after the impossible, in their trials of every mixture and combination which they could think of, could hardly fail to make accidental but useful discoveries. In this way the action of many of our most important chemical agents was revealed long before knowledge was ripe enough to make use of them, or even to grasp their signification.

The four reputed elements have long been relegated to their proper places in nature: air and water being compound bodies, while earth comprises every element as yet known—to the number of about sixty-five. The remaining pseudo-element was fire, which we now recognise merely as a chemical process.

It is not difficult to see how such notions gained currency, for it is only in comparatively recent times that proof by direct experiment has been considered necessary before a doctrine is enunciated. In past centuries a kind of happy-go-lucky system prevailed which first imagined a theory, and then strained things to accommodate themselves to it. We now go to work in a different way altogether, for we first study the properties of bodies, and the theory as to their existence in nature is based on the knowledge thus acquired.

The most common example of the three forms of matter is water, which under different degrees of temperature is either solid, liquid, or gaseous. In a previous article, on "Ice, Water, and Steam," (p. 28), we have learned many interesting things about the behaviour of water under these different conditions; but in the present paper we intend to look upon it more in its relation to chemistry. We have already seen that it was long considered to be an element. What more natural than that such an idea should prevail? A universal agent seen under all kinds of different aspects—in its beauty, as the glittering dewdrop, or the welcome summer shower; or in its forms of terror, as the flood, or the raging sea,—even in the present day the error is handed down to us in that stereotyped phrase, "the Conflict of the Elements." The word "element" has in point of fact two significations, —the one which clings to it from the misconception of past times, and the other which is its true definition, "a simple substance."

The very foundation of modern chemistry rests upon the supposition that all substances are built up of a vast number of molecules (little masses) of matter. These molecules are far too minute to be detected by our sight, but they are nevertheless to be considered as actual particles. In solids these molecules are bound closely together by the force known as "cohesion." In liquids their union is not so close, and they are free to move—the mass of liquid being able to adapt itself to the form of the vessel in which it is placed. But in the gaseous state the molecules are more widely separated, and may be considered as so many different points of matter having interstices between them.

In order to make this part of our subject more clear, let us imagine that a solid is represented by a leaden bullet of a definite weight, and a liquid by the same weight of metal in the form of dust-shot. Now these shot, as they slide and tumble over one another as the vessel in which they are contained is inclined to the one side or the other, will give us a very fair idea of the action of the molecules of a liquid. To represent a gas, we must discharge the mass of dust-shot into space, when of course their apparent volume is much increased, owing to the wide intervals which separate the individual particles of lead from one another; but the aggregate mass of metal remains exactly the same as when it was in the solid state. Although this is necessarily a clumsy illustration of molecular phenomena, we hope that it will help to make clear to our readers the fact that a gas is

but matter in which the particles are more widely separated than they would be in either the liquid or solid form.

It may be difficult to believe this theory of molecules. It would seem almost incredible that matter could ever be divided into portions too minute for our most perfect instruments to detect. But let us consider for a moment how, before the improvements in our microscope, our ancestors might in the same manner have disdained to believe in small magnitudes. Blood, for instance, was supposed to be a red fluid, coloured throughout—like a solution of cochineal. But we now know that it owes its colour to multitudes of bodies having definite size and shape, called corpuscles. We also know that a small drop of this blood will contain about three millions of these corpuscles. Again, the microscope teaches us that there exist animals which are so small that millions of them do not exceed in bulk the size of a grain of sand. We might quote many other instances of the minute divisibility of matter, but we have already said enough to show that the molecular theory is in no way inconsistent because it deals with magnitudes too small for our conception Although these

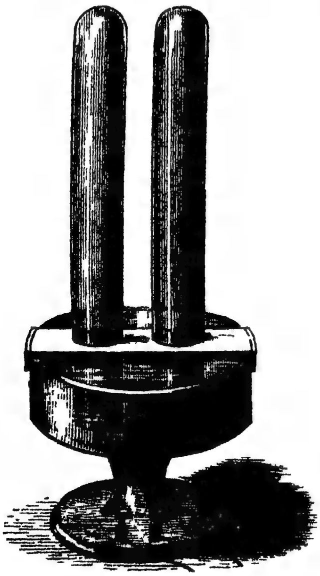


Fig. 1.—Illustrating the Decomposition of Water by Electricity.

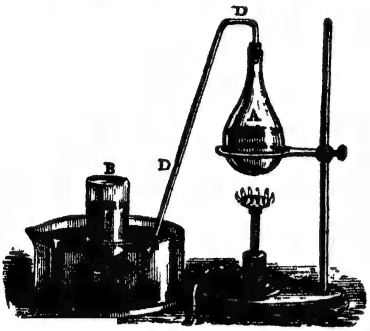
molecules are incapable of physical sub-division, they can chemically be split up into different atoms. We shall now endeavour to show how the molecules of water can be thus separated.

The decomposition of water is effected by a current of electricity, and the operation is called *electrolysis.* Fig. 1 is a convenient form of apparatus for the purpose. It consists of a glass vessel, supported above which are two inverted test-tubes. Immediately beneath each of these tubes is a little strip of platinum-foil, which is connected with its binding-screw placed on the wooden stand of the instrument. When required for use, the body of the instrument and the test-tubes are filled with water, and the two binding-screws are connected by wires with a voltaic battery. Directly the electric current passes, bubbles, which gradually accumulate to displace the water in the tubes, are seen to rise from both the platinum terminals. By examining these tubes, and testing their contents, we shall soon be convinced that the invisible vapour with which they have become partially filled, is quite unlike ordinary air. We shall further discover that the gas in one of the tubes is quite different in character to that which has collected in the other. On applying a lighted match to the first it will burn away quickly with a pale-blue flame. This is hydrogen. The other tube may be tested with the same match after it has been extinguished, but whilst it still retains a smouldering spark. The match immediately bursts into flame, and burns with a much-increased brilliancy. This gas is that wonderful supporter of combustion known as oxygen. By this experiment we ascertain that water, instead of being, as was once thought, an element, is but a compound body, formed by the union of two elements—namely, Hydrogen and Oxygen. Their preparation by the electrolysis of water is, however, a very tardy operation, and quite out of the question when we want large quantities of either gas for experiments. We will therefore give a few plain directions which will enable any one who has the wish, to prepare these and other gases without difficulty or expense.

For the preparation of most of the gases, the roughest and most common appliances are sufficient. It is too much the fashion in text-books to give engravings of apparatus apparently so elaborate that the student is at once frightened from direct experiment, and is content with reading that such and such an effect is produced under certain conditions. He is thus prevented from trying simple experiments, which would cling to his memory long after those which he had only read of had been forgotten. The most valuable discoveries have been arrived at with the very simplest apparatus, and the student who is content with a common Florence oil-flask for a retort, and a pickle-bottle for a gas-jar, is but

following the footsteps of those among us who have made great names.

We shall first of all require a pneumatic trough. An ordinary dish-tub, or large pan, with a shelf fixed by some means a few inches above its bottom, will answer the purpose admirably. This vessel must contain sufficient water to just cover the shelf. We shall next want some glass pickle-bottles, which we must fill with water, and invert over the shelf. This can very easily be managed by keeping the




ing how to obtain Oxygen Gas.

hand over the mouth of each bottle until its neck is submerged, when of course for want of air the water will be retained. Having now our pneumatic trough in position, and the bottles standing on the shelf ready to be filled with gas, we will proceed to describe the operation that is shown in Fig. 2. The Florence flask A (such flasks can be obtained for a few pence, but must be thoroughly washed with dilute acid before being used for the present purpose) contains the composition for making the gas required. D is a glass tube, bent by means of a spirit-flame, so that its further end may dip under the water contained in the pneumatic trough towards the orifice of the inverted bottle B. Beneath the flask—or, more properly, the retort—is a gas-burner, but a spirit-lamp will answer every purpose. The gas is seen rising in bubbles, and is quickly displacing the water contained in the bottle. The most convenient manner of obtaining oxygen is from a mixture of equal parts of chlorate of potash and oxide of manganese. The mixture having been placed in the retort, the spirit-lamp must be cautiously and gradually brought under it, when the gas will soon pass over in great abundance. The first few bubbles which pass will consist of the air contained in the flask, and must be allowed to escape, after which the bottles may one after the other be filled with the gas, and put aside for experiment. The precaution of allowing the contained air of the retort to escape applies to all the gases; otherwise the mixture obtained would in many cases represent a highly explosive and dangerous compound.

The phenomenon which we call combustion is caused by the union of certain bodies with the oxygen contained in the atmosphere. We shall, therefore, be prepared for finding that combustibles placed in undiluted oxygen, such as our pickle-jars contain, will burn with unusual energy. We have already seen that a match bearing the least trace of a spark will, when immersed in the gas, burst into flame. A small lump of charcoal supported on a wire and ignited in the spirit-flame will, when dipped into one of the bottles, exhibit most beautiful scintillations until consumed. The charcoal in this instance combines with the oxygen to form carbonic-acid gas, which may be retained in the bottle for further examination. A piece of iron wire, or watch-spring, which has been tipped with sulphur and inflamed, will also burn away with remarkable brilliancy (see Fig. 3). By filling a bladder or indiarubber bag with oxygen, and fitting to its neck a common blow-pipe, and directing by its aid a stream of the gas upon a rough nail, or any piece of iron held in the flame of the spirit-lamp, the metal will be rapidly consumed. If,

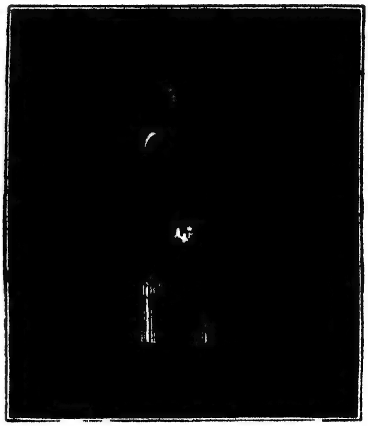


Fig. 3.—Illustrating Combustion.

instead of the iron, we project the gas upon a cylinder of chalk, we shall produce the dazzling lime-light. Fig. 4 shows the arrangement for obtaining this light experimentally; but when required for active service, a special jet is employed, by which a mixed stream of hydrogen and oxygen is urged upon the lime. The heat obtained by this means is so great that platinum, the most refractory of the metals, is quickly reduced to the liquid condition.

Our readers have doubtless often heard the term "ozone" used in comparisons of the health-giving advantages of different sea-side resorts. This ozone

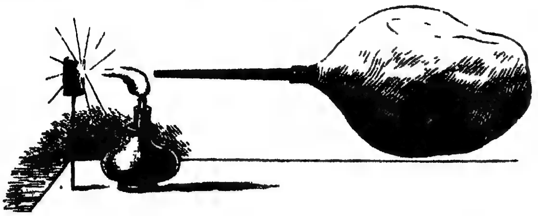


Fig. 4.—Experiment for producing the Lime-Light.

is an altered and condensed form of oxygen, and is commonly noticeable by its peculiar smell when an electrical machine is in use. It can be obtained with special apparatus for passing an electric current through a jar of oxygen, but it changes again to its old form when exposed to a red heat. Paper which has been impregnated with a mixture of starch and iodide of potassium instantly becomes blue if it be submitted to a stream of ozone. This test (albeit a very rough one) has been suggested in estimating the relative amount of ozone contained in the air of different localities. In towns the ozone is absent, being reduced to its parent oxygen by the vapours from our chimneys, and the general emanations which clog the lungs of thickly-populated places. Ozone can be prepared by scraping a stick of phosphorus under water, and placing it in a jar containing a small quantity of the same fluid. After some hours the formation of ozone can be detected by its smell, and by the above-mentioned test. It possesses powerful antiseptic and bleaching properties. The latter may be utilised in the restoration of any discoloured engraving. The picture, being loosely rolled, and placed in the jar with the phosphorus and water, will be gradually rendered perfectly clean. Oxygen was first discovered by Priestley, in 1774. He obtained it by heating red oxide of mercury, the molecules of which split up into metallic mercury and oxygen. It is, perhaps, the most widely-diffused of all the elements. It forms one-fifth of our atmosphere, and about one-third of the solid crust of the earth, and, as we have already seen, it is one of the two constituents of water. We shall now proceed to consider the other gas obtained by the electrolysis of that fluid.

Hydrogen, the lightest of all bodies, is, when pure, a tasteless, inodorous gas. It may be prepared for experiment in a variety of ways. A small fragment of the metal potassium will, on being thrown into water, burst into flame, the metal uniting with the oxygen, and setting free the hydrogen. Sodium behaves in much the same way; and if a small piece of the latter metal be depressed beneath the water of the pneumatic trough, the gas can be collected in a bottle. But the usual way of preparing it for laboratory use is from zinc-clippings. These are placed in a strong vessel, for the heat evolved in the process is very great. An earthenware bottle is, perhaps, the best for the purpose. The zinc is placed in the vessel, and covered with water; after which a small quantity of oil of vitriol (sulphuric acid) is added, and the gas is rapidly given off. The bottle should be fitted with a cork, through which is passed a glass tube drawn to a fine jet, where the gas may be burnt; or it may be collected over the trough in the usual way. The greatest caution must be used in dealing with this gas, for its mixture with air is highly explosive. For this reason, it should not be inflamed for some minutes after the acid has been added to the zinc; and, in the case of the pneumatic trough, the first bottle filled should be allowed to escape.

The extreme lightness of hydrogen may be demonstrated by filling a bladder with the gas, and afterwards fitting to its neck a common tobacco-pipe. By this means soap-bubbles may be inflated, when they will rapidly rise to the ceiling. If a tumbler be held inverted over the hydrogen flame, the gas will combine with the oxygen of the atmosphere, and the glass will speedily be covered with moisture. A mixture of hydrogen and oxygen, in the proportion of two volumes of the former to one of the latter, may be made to combine to form water. But as they do so with explosive force, the operation must be conducted with great care. A strong soda-water bottle containing the mixed gases must be wrapped in a cloth. Upon its open mouth being presented to a flame, a loud report is heard, and if the bottle remains unbroken, a small quantity of water in the form of dew will have collected on its sides.

The oxy-hydrogen blow-pipe, to which we have already briefly alluded, is capable by its intense heat of liquefying and volatilising all the metals, and even such substances as rock-crystal and clay. The mixture of the two gases forms such an explosive compound that a particular form of burner is used, so constructed that they are not allowed to mix until they reach the place of ignition. Fig. 5 shows the principle of the jet commonly employed, H being the supply-pipe for the hydrogen, and O for the oxygen. The lower part of the figure exhibits the kind of furnace used for

the reauction of platinum. It consists of two fire-bricks hollowed out for the reception of the metal, with an orifice above for the introduction of the blow-pipe flame.

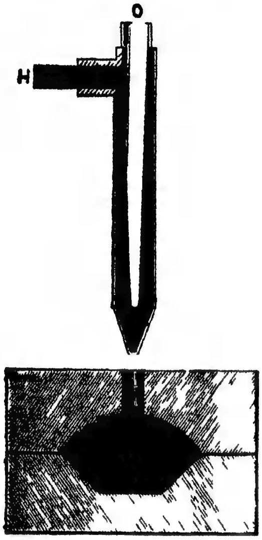



Fig 5.—Showing the Oxy-Hydrogen Burner and Furnace for reduction of Platinum, &c

Hydrogen is present in all organic substances. Although it is presented to us as a compound with other matter, as in water, we have evidence through the wonderful revelations of the spectroscope that it exists in the atmosphere of the sun in a free state.

Having now examined separately the constituents of water, we may proceed to inquire into the nature of that wonderful gas called nitrogen, which forms four-fifths of the air which we breathe, the remaining fifth consisting of oxygen. We can best obtain the former gas by robbing a given amount of air of its oxygen, when nitrogen will remain. Phosphorus is a substance which has such an affinity for oxygen that it will combine with it very readily, leaving the nitrogen of the atmosphere in

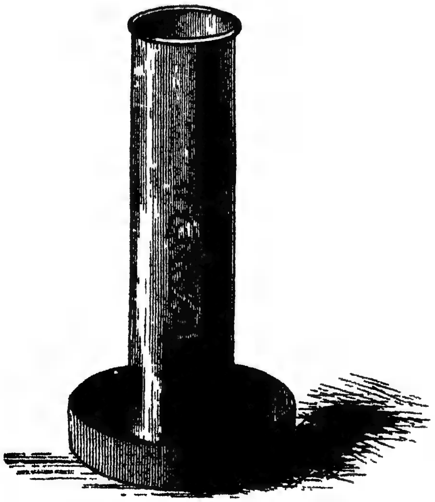


Fig 6.—Experiment for obtaining Nitrogen.

which it is burnt untouched. The experiment may be arranged as follows (see Fig. 6) :—A small piece of phosphorus carefully dried upon blotting-paper is placed in a porcelain cup, supported on a stand in a dish of water. The phosphorus is ignited with a hot wire, and the whole is quickly covered with an inverted glass jar.[1] The jar should have pasted upon it a graduated paper scale, such as doctors attach to their physic-bottles, dividing it into five equal parts. It will be found that when the phosphorus is burning the water will rise in the jar exactly one-fifth, showing that that amount of air —really its oxygen—has disappeared, leaving the nitrogen for our examination. A lighted taper, on being placed within the jar, is immediately extinguished, and the gas will not support animal life. But it cannot be considered poisonous in the sense that some of the gases are, for we know that we are always breathing it. Although nitrogen in its free state is quite inert, it is in its combined forms quite as much associated with the phenomena of life as its yoke-fellow oxygen. It is the invariable constituent of all organic substances, both animal and vegetable. The former gather it from the latter, to be again returned to the soil from which it originally came. Nitrogen is also the active principle in all explosives, from gunpowder to nitro-glycerine.

The mixture of nitrogen and oxygen, upon which our lungs depend for their food, is simply mechanical, not chemical. A chemical combination is understood to happen when two substances unite to form something perfectly new in character. This, we have already seen, cannot be the case with atmospheric air, and when we had eliminated the oxygen by means of phosphorus, the nitrogen remained unaffected by the operation. But the

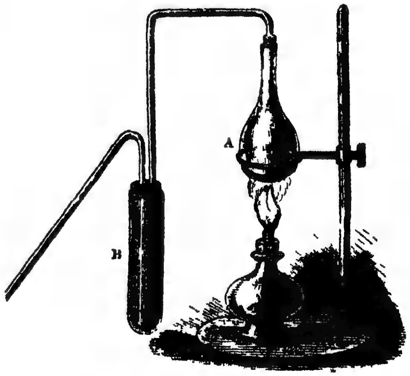



Fig 7.—Experiment for obtaining Laughing-Gas.

same two gases can be made to combine *chemically* when it will be found that the product is totally different from either. We must arrange the apparatus as in Fig. 7. The flask A contains a small portion of the white salt known as nitrate of ammonia, which is a combination of nitrogen, oxygen, and

hydrogen in certain proportions. When heat is applied, the hydrogen and part of the oxygen combine to form water, which is intercepted by the test-tube B. The remainder of the oxygen combines with the nitrogen and passes off as gas to the pneumatic trough. This is nitrous oxide, more commonly known as laughing-gas. It is now largely used by dentists, and in minor surgical operations, as a safe and convenient anæsthetic. We have here exhibited the singular phenomenon of two elements uniting *mechanically* to furnish us with the air we breathe, and combining *chemically* to produce an intoxicating gas which, unless used with discretion, is an actual poison.

We need but briefly refer to carbonic acid—that curious compound of carbon and oxygen upon which plants feed, but which is so fatal to animal life—for it has already been fully discussed, and its preparation described in another article.* Its most noticeable feature is its extreme heaviness, which may be well shown by half-filling an open basin with the gas, and causing a child's indiarubber ball, or a soap-bubble, to rest upon its surface. To the uninitiated the ball seems to be suspended in mid-air (see Fig. 8).

An inflammable gas is often found issuing from

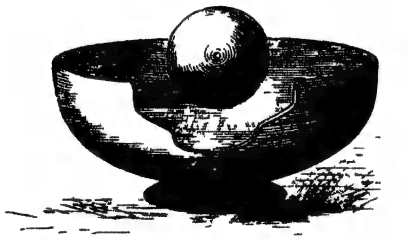


Fig 8.—Experiment showing Heaviness of Carbonic Acid.

the ground, more especially in the neighbourhood of stagnant water and decaying vegetable matter. Legends as to "corpse-candles" and the fugitive "Will-o'-the-Wisp" may all be set down to the credit of this compound, which is known by the characteristic name of "marsh-gas."

We too often read of colliery explosions, where in a moment hundreds of human beings are hurried into eternity, leaving perhaps treble that number who were dependent upon them to mourn their loss. As a great deal of misconception exists as to the actual nature of these calamities, a few words as to the character of the terrible gas which causes them will not be out of place. We must remember that the coal-formations are the result of vast accumulations of decaying vegetable matter, which under a tremendous pressure has been converted into the well-known black fuel. It is not surprising that quantities of marsh-gas, the product of the slow decomposition, should be pent up in every cavity existing in the coal-beds. In some seams this gas *whistles* out of the mineral directly the pick is applied to it. Among the miners this is known as "singing coal." "Fire-damp," a word which we have learnt to regard with so much dread, is merely another name for marsh-gas. On mixing with atmospheric air, its explosive qualities are even greater than the mixture of hydrogen and oxygen already referred to. Moreover, in exploding, it leaves all the air in its vicinity quite unfit for respiration; so that those who are not killed by the explosion of the fire-damp, succumb to the deadly effects of the "after-damp," which is simply carbonic acid.

Although, as may be imagined, marsh-gas is nearly allied to that which we obtain from the distillation of coal, it is very unlike it in one important particular—for it is totally without odour. It therefore steals upon the poor miner without the well-known warning which fortunately accompanies an escape of gas in a dwelling-house.

The preparation of coal-gas may be effected in miniature by means of a common "long clay" tobacco-pipe. The bowl must be nearly filled with coarsely-powdered coal, and must be sealed up with a cover of moist clay. When the clay has sufficiently dried, the bowl must be exposed to a red heat in an ordinary fire-grate. The gas, with a quantity of smoke, will soon be generated, and can be lighted at the mouthpiece of the pipe. The residue left in the now red-hot bowl of the pipe, is a lump of nearly pure carbon in the form of coke.

In our gas-works, the crude gas, when conveyed from the retorts, has to undergo a purification by means of lime; but, unfortunately, it generally retains many constituents which do not add to its brilliancy, and which are positively injurious to health. We cannot here enter into a consideration of the various by-products of the gas manufacture; but they are of a most interesting and important nature. The lovely aniline colours may be reckoned as not the least valuable.

The gas which now claims our attention is, from its green colour, called *chlorine*. It is a most plentiful agent in nature; indeed, its union with the metal sodium results in that familiar compound common salt. In its pure state its inhalation would be followed by immediate suffocation, so that the greatest caution must be used in dealing with

* See "Fresh Air and Foul Air," p. 217.

it. But, diluted with a large quantity of air, it smells of fresh sea-weed. There is no gas which, in the hands of the experimenter, exhibits more interesting and wonderful phenomena than chlorine, and the slight trouble and inconvenience which its preparation entails, is amply repaid by the results gained.

A table-spoonful of common salt (chloride of sodium) is mixed with an equal weight of the black oxide of manganese, the latter being the same compound which we have already used for the production of oxygen. Half a tea-cupful of sulphuric acid is mixed in a separate vessel with an equal quantity of water, and allowed to cool. The two mixtures are then combined, placed in the retort, and heat is applied. The pneumatic trough should be used with *hot* water in the operation, as this gas is very soluble in cold. The first product of the mixture must not be allowed to escape into the room, for a severe fit of coughing on the part of the operator would be the inevitable result. Besides, this diluted portion, if collected in a bottle, is quite serviceable for showing the bleaching action of the gas.

A piece of glazed calico, blue or red paper, natural flowers, or indeed any coloured material which owes its hue to vegetable sources, is immediately whitened in this gas. They should first be moistened in water, as chlorine is almost powerless when dry. The prosperity of Manchester and Glasgow is mainly due to the bleaching of cotton goods, which is carried on there by the help of chlorine, in the form of the well-known "bleaching-powder," commonly called "chloride of lime." The process consists in dipping the unbleached or "grey calico" into a solution of the lime, and then into a bath of water made sour with sulphuric acid. This is repeated, and a good washing in a running stream completes the operation. The fact that chlorine does not bleach carbon or mineral colours, may be illustrated by dipping a printed card into common ink. When dry, this card can be submitted to the action of the gas, when the ink will soon disappear, leaving the printed matter untouched.

A piece of Dutch-metal, or leaf-gold, placed in a jar of chlorine, will immediately take fire. Finely-divided antimony will cause the same result (see Fig. 9). Hydrogen will also combine with chlorine, with the evolution of light and heat. This may be shown by placing in the jar a piece of blotting-paper soaked in turpentine. The hydrogen of the turpentine will unite with the chlorine, while its carbon will take the form of soot.

But a still more striking manner of causing the union of hydrogen and chlorine is to mix—in a *darkened* room—equal quantities of the two gases

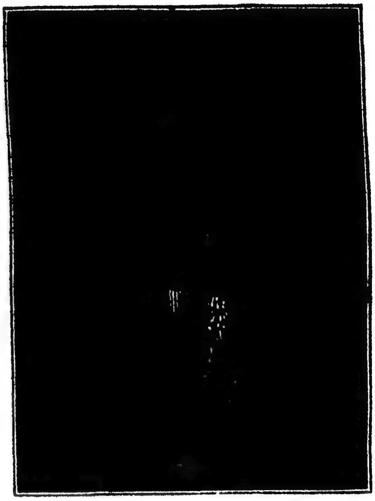


Fig. 9.—Showing powdered Antimony burning in Chlorine.

in a very small and thin glass flask. For safety, cover this flask with an ordinary wire dish-cover, and expose the whole either to direct sunlight or to the rays of a piece of burning magnesium wire (see Fig. 10). The gases will combine with explosion, and the glass in which they were placed will be shattered to pieces.

The belief now generally entertained that hydrogen is a metal, is strengthened by its explosive union with chlorine, which resembles so much the behaviour of other metals under the same conditions. Chlorine, like carbonic acid, is much

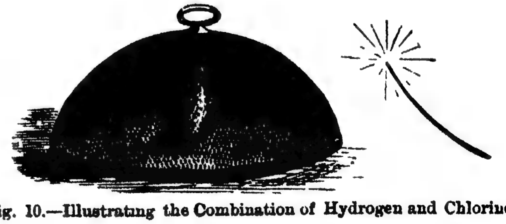


Fig. 10.—Illustrating the Combination of Hydrogen and Chlorine.

heavier than air, so that the stoppers of the bottles containing it may be removed for experiment without loss or inconvenience. It is one of the elementary bodies, and was first discovered in 1774, by Scheele.

Not the least remarkable property of gases is their power of blending with one another. If equal volumes of the three separate gases—hydrogen, nitrogen, and carbonic acid—are decanted into

one large jar, it might be expected that they would naturally arrange themselves in distinct layers: the first-named, on account of its lightness, occupying the upper part of the vessel, the carbonic acid sinking to the bottom, and the nitrogen remaining suspended between the two. Such, however, is not the case, for every portion of the jar will be found to contain an equal mixture of the three gases. The importance of this law of diffusion will be apparent when we think of the consequences which would ensue were the large amount of carbonic acid, which is constantly arising from our earth, retained near its surface. Animal life, under such circumstances, would, of course, be simply impossible. For the laws relating to gaseous volume, we must refer the reader back to page 72, where he will also find much that is interesting concerning molecular movement.

It has long been the opinion of chemists, that with sufficiently powerful apparatus all the gases could be compressed into a liquid state. Faraday was the first to experiment in this direction. In his hands, a number of the gases which up to that time had been considered permanent, were reduced to the liquid and even solid state. But three of those with which we have been experimenting—namely, hydrogen, oxygen, and nitrogen—resisted all his efforts. We shall find in all the text-books published up to the close of 1877, that these gases are described as "permanent." The apparatus which Faraday used was a bent tube (see Fig. 11). In one end he put the mixture from which the gas was to be evolved, while the other bulb—previously sealed up in the flame of a blow-pipe—he placed in a freezing-mixture. When heat was applied to the former, the pressure which ensued—added to the extreme cold applied to the other bulb—caused the gas to collect there in a liquid form. Since New Year's Day, 1878, the three so-called permanent gases have, by means of most powerful apparatus, been made to succumb, and there is now no such thing known as a permanent gas. A stream of liquid oxygen was seen, which caused anything brought within its influence to burn with terrific violence, and hydrogen, of a steel-blue colour, was thrown out of the apparatus, and pattered on the ground like so much hail. It followed as a matter of course that the compound of nitrogen and oxygen,—*i.e.*, common air, could also be compressed; and liquid air was actually produced. The liquefaction of these gases is one of the triumphs of modern times.

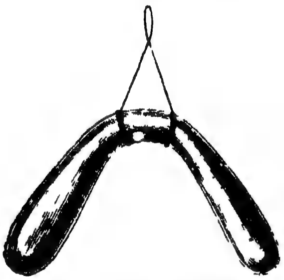


Fig 11—Apparatus used by Faraday.

In conclusion, it must be observed that the gases which we have chosen for consideration must not be looked upon as merely the products of the laboratory. Although they are strange to us in their free state, combined they are intimately wrapped up with our daily lives—with the air we breathe, with the water we drink, and with all the food on which we depend. Nay, the very tissues of our bodies, when reduced to their constituents, may be proved by experiment to be identical with these vapours which we have been imprisoning in bottles, leaving only a small residue of ash—earthy matter—to represent the dust to which we must all return.

## THE IRISH ELK AND ITS ENGLISH CONTEMPORARIES.

By A. Leith Adams, F.R.S.,

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THE phenomena relating to the Glacial Period, or Ice Age, described in a previous contribution (p. 33), clearly establish the presence of an arctic climate in the British Islands, at an epoch not very remote when determined by the method of computing time adopted by geologists; or, in other words, by comparisons of the characters of the mineral strata, and of the animal or vegetable remains preserved in them. Indeed, were it not for the testimonies furnished by rocks and soils, we should know very little of pre-historic times; but by investigating the appearances and structure of the mineral portion and the relations of the various beds to one another, the student is enabled to determine with considerable accuracy past changes in the relative position of sea to land, whilst the remains of plants and animals entombed in them furnish evidences of the climatic conditions and

physical geography on the one hand; and the position and extent of lands now submerged under the ocean (p. 132) on the other. Moreover, by bringing together suchlike witnesses from different regions, he will be in a position to construct chronological documents by which the various strata can be arranged in accordance with their order in time; thereby indicating when lands disappeared or were re-elevated. But although the geologist has not the means of establishing positive lengths of time, still, sufficient proofs can be obtained to show that the history of our planet is made up of ages and periods characterised by their peculiar animal and vegetable products, and also for the most part by their rock structures.

The plants and animals which perished during the accumulation of the rocks and soils, either on dry land or on the sea-bottom, have been preserved in accordance with the hardness or other peculiarities of their structures; so that vast numbers of soft-bodied animals and perishable plants have totally disappeared. The records of the rocks must therefore be considered very imperfect as far as is yet known; but they nevertheless furnish irrefragable proofs of the animal and vegetable life of the various epochs to which they refer. By means of even certain groups of animals, such as marine and fresh-water shells, and particular assemblages of terrestrial animals, whose remains may happen to have been preserved in fossilised or petrified conditions in the strata, the student is enabled to determine whether they were natives of arctic, temperate, or tropical climates; and, from their organisations, what were the likely condition and extent of the flora and physical geography of the sea or land on which they sojourned. By a similar method we propose to elucidate that portion of the history of the British Islands known as the Post-Glacial Period, or, in other words, the progress of events which followed the Ice Age (p. 39), and has culminated in the Present or "Recent" Period of geologists.

In selecting a group of animals for the purpose of elucidating past changes of the surface of any particular region, a preference must always be given to mammals or suck-giving animals, for the following reasons:—They are the most generally distributed over land and water, they suit themselves to climate and locality, and are not subject to accidental distribution; whilst they are not dependent on other groups of animals. Their bony parts preserve well, consequently they have left abundant traces of their presence in the latest geological formations. We shall therefore confine our observations to the mammals of the Post-Glacial Period, as manifested by discoveries of their remains in the deposits of limestone caverns, and in the silt and detritus of the rivers, lakes, and sea-bottoms connected with the British Isles.

The evidences they furnish of past changes in the relative positions of land and sea, relate to the numbers and particular descriptions of quadrupeds, as compared with similar remains met with under like conditions on the Continent of Europe and elsewhere. By far the greater portion of animal relics have been dug up from deposits of limestone caverns in England and Wales. These rock cavities are the products of atmospheric and aqueous agencies acting on the calcareous strata, so that what may at first have been a mere crack or fissure will become in time a cavern. The process of erosion is partly chemical, inasmuch as the rain-water impregnated with carbonic acid received from the air acts as a dissolvent on the lime, scooping out, by a very slow but certain progress, galleries and tunnels often of surpassing magnitude and extent, and of wondrous construction. These tunnels, following, for the most part, the directions of the rock rents, may present every variety of outline; whilst the constant dripping of water saturated with lime forms a calcareous cement on the floor, where it rapidly solidifies and becomes very effective in preserving the animal and vegetable relics with which it may come in contact. To this substance the name *stalagmite* has been given; whilst the icicle-like masses of the same substance, often seen depending from the roofs and sides, and frequently of beautiful and fantastic shapes, have been called *stalactites*.

Now, supposing that such a rock cavity became the den of wolves or hyænas, we may easily suppose that the fragments of the bones of the animals on which they preyed, and their own skeletons, if any happened to die in the cavern, would be apt to get covered up by this constant lime-dripping going on from the roof and sides of the den. But the process of interment would not be altogether confined to this agency, for through the various rents in the roof and sides, and also by the entrance, surface-soil, clay, and other materials conveyed in by water and deposited on the stalagmite, would form a new floor, and thus the relics of the period of the carnivorous animals would be completed. The second stage in the history of the cavern now commenced. Man may have made it a temporary or a permanent residence, and being a hunter, was certain to have brought the bodies of his victims into the

den, where the refuse of his feasts, and the stone and bone implements of the chase, got occasionally mingled, whilst the dripping of stalagmitic material was still going on, and the above were sharing the fate of the relics of the wolves and hyænas. At length the cavern was abandoned by man, and new occupants took his place, until, nearly filled to the roof by the accumulations of years, it finally became the abode of the fox, or formed a rabbit-warren. In corroboration of this method of preserving animal relics, the following example will serve as an illustration.

During the year 1821, when workmen were employed in quarrying a limestone rock at Kirkdale, near Pickering, in Yorkshire, they broke into a cavern, the external entrance of which was closed at the time with earth and other materials. In this cavern there were found vast quantities of broken bones and teeth. Some were more entire than others, but the generality were in fragments, and, from markings on them, showed that they had been gnawed and smashed by the teeth of large flesh-eating quadrupeds. Besides the bones there were many small balls, which, on careful examination, turned out to be the excrement of some creature that had fed on the bony parts of other animals. A careful examination of the collection, which was very extensive,

Fig 1.—Skull of the Cave Hyæna

showed that the majority of the relics belonged to a hyæna of large size as compared with any now living, so that Kirkdale Cavern had in all likelihood been a den frequented by carnivorous animals, chiefly hyænas (Fig. 1), which had dragged portions of their victims into its dark and dank recesses. Among the stalagmitic earth, and strewn about like the refuse on the floor of a dog-kennel, were quantities of bones and teeth of quadrupeds, many of which are now totally extinct, whilst a few still frequent foreign countries, and a moiety survive on British soil. Of the first, there was a gigantic stag, known as the Irish elk, exhibited by parts of its skeleton; also the so-called ancient elephant, a rhinoceros, a hippopotamus, a bison, and

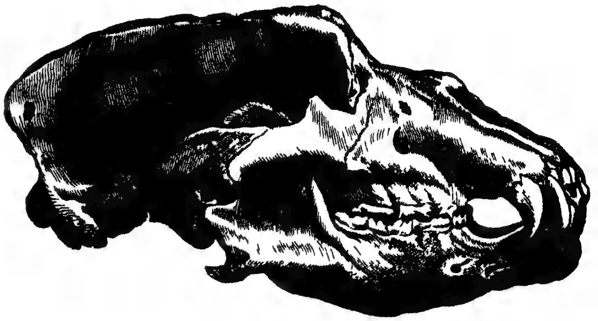


Fig 2.—Skull of the Great Cave Bear

wild horse. Besides these, the lion, spotted hyæna, brown and grisly bears (Fig. 2), the wolf, and reindeer, now driven to tropical or cold regions, and the red deer, fox, rabbit, hare, and water-rat, which still maintain their footing on British soil. Now, these animals represent only a small portion of the mammals which frequented Great Britain during the Post-Glacial Period, as is testified by the records of similar rock cavities in other districts of England and Wales, such as the well-known Kent's Cavern, in Devonshire, where remains of thirty species of living and extinct mammals have been discovered, as also in other rock cavities in South Wales, Derbyshire, and elsewhere. Among these remarkable extinct animals, remnants have been found of a formidable lion with sabre-shaped canine teeth. This monster has left its bones and teeth in the rocks, soils, and caverns of various other countries, including even the caverns of Brazil. Altogether, the records of the English bone-caves tell a strange story in connection with the islands, at the time when these animals roamed over the hills and valleys—to wit, how the rhinoceros and hippopotamus wallowed in the rivers; of herds of divers sorts of elephants, oxen, deer, and the wild horse, that frequented the forests and glades; and of the lions, panthers, hyænas, and wolves, which preyed on them; and, lastly, of man, who seems to have played no unimportant part in the work of extermination, as will be shown in the sequel. Further, to have maintained such a numerous and varied animal life, there must have been ample vegetable subsistence. They likewise indicate extensive feeding-grounds, and a connection at that time between Great Britain and the Continent of Europe, where all these animals' remains have been

discovered under similar conditions, and where, as in England, there is evidence to show that they existed even before the Glacial Period.

We come now to the evidences furnished by the deposits of rivers. During the thaws that must have characterised the close of the Ice Age, and continued for longer or shorter periods throughout the long vista we are considering, the rivers and inland lakes were doubtless subject to constant inundations which covered large tracts of country, and formed the extensive deposits of sand, loam, and clay, in which the remains of several of the above-mentioned and other animals are found. Indeed, it is now generally believed that many of the insignificant streams of our islands are but the tributaries of much larger rivers that existed during Post-Glacial times, and before the severance of the island from the mainland. The Thames, for instance, is thought to have been one of the branches of the Rhine. London, again, is built on deposits laid down by the Thames; and in many other situations, where insignificant streams now exist, the surrounding water-shed shows enormous beds of river-silt and gravel, which contain remains of the above and many other Post-Glacial mammals, accompanied by river shells and evidences that leave no doubt as to how they had been deposited.

Between Oxford and the mouth of the Thames, in the brick-earths, sands, and gravels of the river-valley, entire skulls and many bones of the woolly elephant or mammoth have been found; indeed, so numerous have been the discoveries that the writer was enabled to recognise teeth of upwards of 500 individuals in public and private museums. Even from the brick-fields of East London, at Ilford, molar (grinding) teeth were collected, belonging, at the lowest possible estimate, to as many as 150 elephants. The mammoth, or wool-covered northern elephant (Fig. 3) was the most conspicuous of the large extinct mammals belonging to the Post-Glacial Period, and seems to have been widely distributed. With the exception of the more mountainous parts of Scotland, it appears to have been generally abundant throughout England and Ireland; and besides leaving many traces of its existence throughout Europe, as far south as Spain and Italy, entire carcases, with the flesh and hair on the bones, were discovered many years since in the frozen soils of

FIG. 3.—IDEAL EUROPEAN LANDSCAPE OF THE POST GLACIAL PERIOD, SHOWING THE IRISH ELK, WOOLLY ELEPHANT, HAIRY RHINOCEROS, URUS, CAVE BEAR, AND CAVE HYÆNA.

Siberia, from whence its fossil tusks and teeth are still imported in quantities for the London market. Again, still farther eastward, around Behring Straits and in Alaska, its skeleton has been found in connection with bones of the reindeer, wild oxen, and horse, or, in fact, the same animals with which it was contemporary in Great Britain; it has even been traced to Canada and the United States.

Another denizen of the Thames valley was a hairy rhinoceros (Fig. 3), whose carcase has also been found under similar conditions and in the same region with that of the mammoth. But one of the most conspicuous objects found in these old flood deposits of our famous river, is the skull of the urus, a gigantic ox (Fig. 4), a magnificent series of which, from the Ilford brick-fields, occupies galleries of the British Museum. Some conception of the formidable proportions of this primeval tenant of ancient British forests may be gathered from the size of its horn-cores, each of which shows a measurement around the curve of 3 feet, with an intervening breadth of forehead of no less than a foot. The same bison which left its remains in Kirkdale Cave reappears in Thames earths and gravels, along with the *exuviæ* of the bear, lion, Irish stag, hippopotamus, and horse. The horse seems to have been generally distributed over the British Islands, and judging from the size of its bones, was not large as compared with our domesticated breeds; but, like many contemporary animals, the period of its extinction is unknown. The beaver, now repelled to northern latitudes, and the most secluded parts of Central Europe, built its dam on the Thames and on many other British streams, as testified by numerous remains of its skeleton found under the streets of London and elsewhere, in connection with the relics of the above and other lost mammals, and it lingered on in Welsh and Scottish rivers up to the eleventh and twelfth centuries.

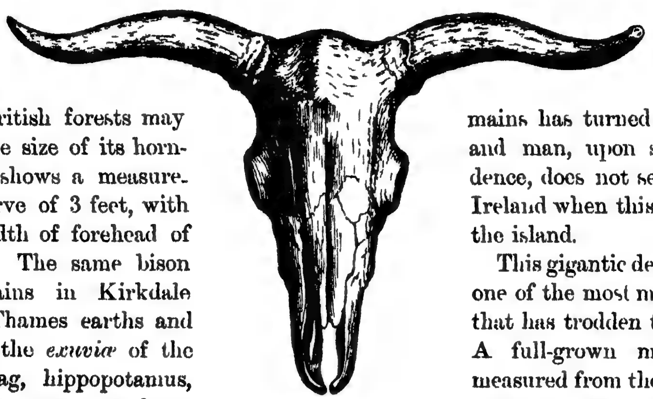


Fig. 4.—Skull of the Urus.

We have now to consider the nature of the animal relics from turbaries and lake deposits; and nowhere can better evidences be procured than in Ireland, which, although prolific in the numbers of relics of its famous stag, has not hitherto produced any great variety of extinct species, as compared with the sister island. Whether the physical aspect and climate of the country then were uninviting to certain mammals not plentiful at the time in England, it seems apparent that Ireland for some time after the Glacial Period was covered by a network of lakes, in which its noble ruminant was in the habit of getting mired. The remains of the Irish elk, hitherto discovered in the shell-marl of peat-bogs, represent many thousands of individuals, and their skeletons have been found in a perfect state of integrity, without even the loss of a single bone. Moreover, unlike the fragments of the same animal met with in English caves, they show no traces of violence from either man or beast. Indeed, the only carnivorous quadrupeds at all likely to have preyed upon so formidable an animal were the bear and wolf, for neither the lions, panthers, nor hyænas, which then frequented England, appear to have found their way to either Scotland or Ireland; at all events, not a trace of their remains has turned up in either country; and man, upon similar negative evidence, does not seem to have inhabited Ireland when this ruminant frequented the island.

This gigantic deer was unquestionably one of the most magnificent quadrupeds that has trodden the face of our planet. A full-grown male, standing erect, measured from the summit of the antler-crown to the ground as much as 14 feet, with a breadth of horn equal to 12 feet, whilst his height at the withers generally exceeded 6 feet (Figs. 5, 6). The dried skull and horns often weigh 95lb., so that in the flesh he must have frequently borne a weight on his neck of fully a hundred pounds. This, with the enormous spread of horn, placed him, no doubt, at a disadvantage, either when swimming across the lake or in making his way through the forest. Indeed, as regards the enormous horn being a likely cause of the destruction of the animal, there is the evidence afforded by the marked absence of the hornless skull of the female and of young individuals; but what is, perhaps, still more suggestive is the extreme rarity of skulls of male individuals after their antlers have just been shed, and before the new annual growth has made any progress; indeed, the bulk of collections show full-grown and aged males, with their horns in their prime. Now, if the same law as to the shedding of antlers obtained in this instance as in living stags, it indicates that the majority of Irish

elks perished in the autumn season, when Landseer depicted his famous pictures of the red deer as seen in the "Challenge," the "Stag at Bay," and the "Monarch of the Glen;" but what would the most stately modern monarch of a Scottish glen have been to this gigantic Irish stag? A conception of the vast quantities of the remains of the latter found in Ireland may be gathered from the fact that in the shell-marl under a bog near Dublin, and in a space of not more than one hundred square yards, no less than a hundred heads and very many bones—indeed, entire skeletons—have been lately dug out.

Now, these discoveries of remains of gigantic deer, as well as of bears, reindeer, and other mammals, in similar lake-beds and under precisely the same conditions, present some important historical features. In the first place, these ancient lakes were formed in what has been named *glacial clay*, in consequence of having been deposited by melted ice of the Glacial Period. During the slow silting up of the bottoms of these tarns by the entrance of soil by streams and the scourings of the surrounding water-shed, many land and fresh-water shells were buried in the mud, which is now in repute for top-dressing to fields, and in consequence of the quantities of its shells has been named "shell-marl." The above might therefore be called the Lake Period, inasmuch as all the large Post-Glacial mammals of Ireland disappeared when these inland water-basins began to dry up, and peat formed on their surfaces; indeed, it would appear that the climatic conditions requisite for the growth of peat may have been absent at that time. At all events, instead of the remains of these early British mammals, we find nothing but bones of the red deer and domesticated animals, which had been mired at much more recent periods. Thus the Irish bogs represent two distinct epochs in the history of the island.

The testimonies afforded of the ancient extensions of the British Islands by the animal relics recovered from the bed of the North Sea, and at various other points along the coasts, are both numerous and interesting. On the east coast of England, from Flamborough Head to Dover, and as far out at sea as dredgers and trawlers are in the habit of proceeding, vast collections of teeth and bones have been found of the large extinct animals just mentioned—more especially of elephants. Indeed, it is no exaggeration that a cart-load of teeth of the woolly mammoth were dredged up on the Dogger Bank alone, whilst portions of the skeletons of no less than four hundred individuals were reclaimed from the sea-bottom off the coast of Norfolk in twelve years. And similar evidences of the old connection of our islands with the European Continent have been obtained from the shallow portions of the English Channel; whilst precisely the same relics are met with on the opposite coasts of France, Belgium, and Holland. Again, skeletons of the Irish elk were discovered in the Post-Glacial clays of the Isle of Man, and bones and teeth of the mammoth elephant were found during excavations in the harbour of Holyhead. The same animal's remains have turned up on the coast of Antrim, in the basin of the Clyde, in the Bay of Galway, and, in certain instances, along with bones of the Irish elk, the horse, and the reindeer.* Finally, with reference to evidences furnished by soundings: The narrower parts of the Irish Channel are not over 360 feet in depth, whilst the English Channel is rarely anywhere more than 300 feet, being less than 200 feet between Dover and Calais. It would appear, therefore, to be evident that, supposing the depression of the intermediate areas was slow, Ireland became an island before Great Britain, and before the animals which had spread over England had time to push westwards; and this belief is further strengthened by the following facts relating to its animals. Out of 44 terrestrial mammals now living in England, 31 are found in Scotland and 22 in Ireland. Again, as many as 33 species of extinct mammals belonging to the Post-Glacial period have been identified from remains discovered in England; of these, however, only 10 have been met with in Scotland, and 7 in Ireland. The great bulk, therefore, of the extinct mammals of the British Isles belonged to England. A remarkable circumstance with reference to the living and extinct species of Scotland and Ireland is that, with one unimportant exception, the mammals of the latter are precisely the same as the Scottish, which might indicate that Ireland received its animal denizens from Scotland, or, in other words, that the original land communication between Ireland and Great Britain was by South-western Scotland and North-western England. At all events, the fauna would seem to show that the severance took place before the animals inhabiting the same latitudes in England had time to make their way to Ireland. Supposing we take the slow-travelling animals and birds of feeble flight; it will be found that there are twice as many

* The reindeer is said to have frequented the North of Scotland about the middle of the twelfth century. In 1158 Jarl Rögnvald was slain at Calder, in Caithness, when hunting it.

species of frogs and reptiles in England and Scotland as in Ireland. The tardy mole and toad are not found in the latter, nor is the dormouse, which, however, is also absent from Scotland; also the water-rat, the hare, roebuck, and several other Scottish and English mammals, whose absence it would be difficult to account for on any other hypothesis. Finally, the extinct quadrupeds hitherto recorded from Ireland are just the very less vagrant denizens of the river-banks and forests, such as the river-horse, the rhinoceros, the wild bull, and of course the lions and large carnivora which preyed on them, may have contented themselves with the luxuriance of the plains of England, Northern France, and Belgium, whose climate was probably more congenial to their tastes.

It has been inferred by geologists that the Post-Glacial Period was characterised by considerable

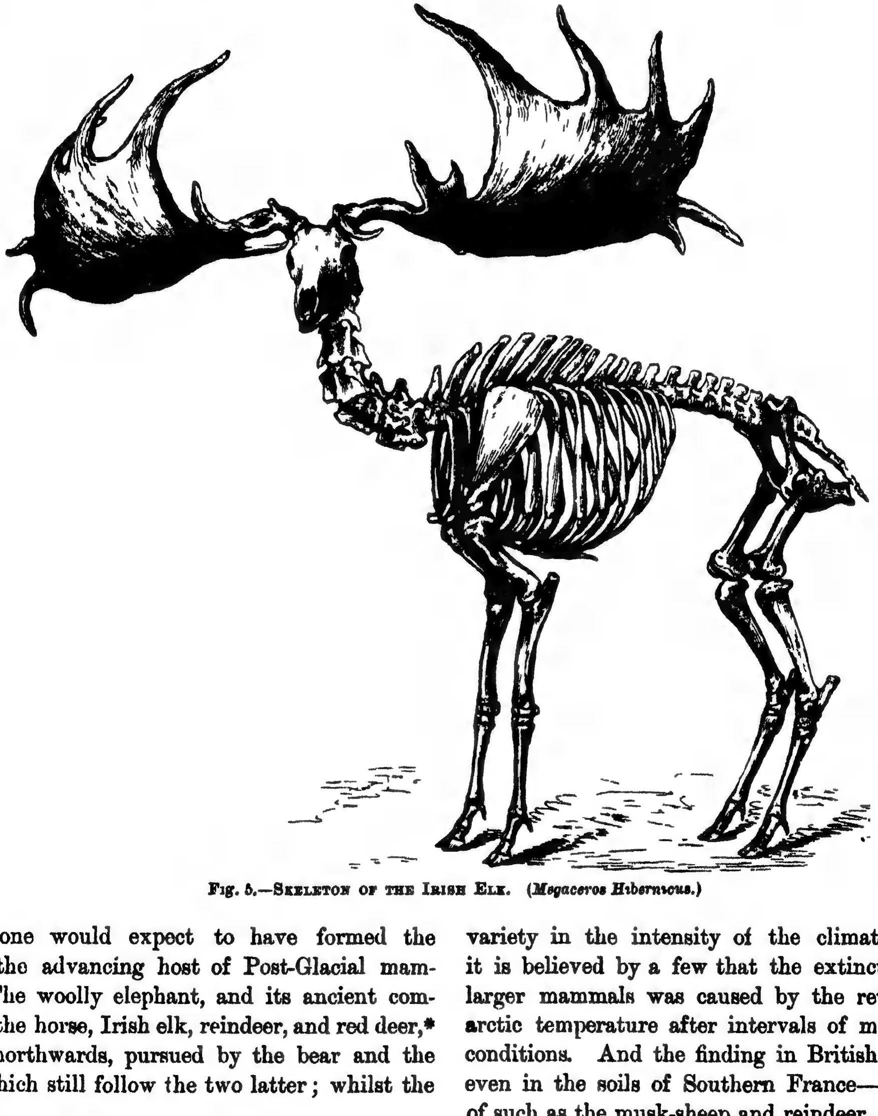


Fig. 5.—Skeleton of the Irish Elk. (*Megaceros Hibernicus.*)

species one would expect to have formed the van of the advancing host of Post-Glacial mammals. The woolly elephant, and its ancient companions the horse, Irish elk, reindeer, and red deer,* pushed northwards, pursued by the bear and the wolf,† which still follow the two latter; whilst the variety in the intensity of the climate; indeed, it is believed by a few that the extinction of the larger mammals was caused by the return of an arctic temperature after intervals of much milder conditions. And the finding in British soil—nay, even in the soils of Southern France—of remains of such as the musk-sheep and reindeer, which now inhabit the polar regions, and of the hippopotamus, rhinoceros, lion, and hyæna of the tropics, appears

* The two latter have still a wide distribution, and the reindeer comes as far south as the fortieth degree of north latitude in North America. Few mammals make more extensive migrations than the reindeer.

† The wolf was exterminated in England about the year 1600, and in Scotland about eighty years subsequently, whereas it lingered on in Ireland till 1710. The brown bear is reported to have become extinct in England early in the ninth century, and in Scotland about the middle of the eleventh century. There is no historical evidence of its residence in Ireland.

to confirm this view. But the discoveries already referred to of the carcases of extinct elephants and rhinoceroses, clad in thick coats of hair, show that although their living representatives are naked, such was not the case with certain denizens of the period we are now considering. Therefore, unless there had been a sudden setting in of cold, so as to kill off the animals before they had time to retreat to more genial climates, the probability was that they were amply provided with all necessary requirements as regards the means of protection against the ordinary rigours of climate; indeed, we may believe the ancient British lion, like the living tiger of the colder regions of Northern Asia, was clad in a long fur mantle, which would have added very much to the formidable appearance of the ancestral king of beasts, whose conspicuous mane and flowing tresses were doubtless far more extensively developed than even in the present leonine denizens of Africa. But the reindeer, wild oxen, and asses of Tartary, and the zebras, antelopes, lions, and other mammals of Central Africa, perform regular migrations, according to the failure of food-supplies, so that the denizens of Britain during the first Glacial Epoch may have retired and advanced annually, as the cold and hot seasons came and went.

It is highly probable that the larger mammals arrived on the British area before man. He is not likely to have pushed northwards in a country destitute of ample means of subsistence. But it is evident that he lived at the same time, and preyed extensively on the herbivorous quadrupeds, and no doubt played a considerable part in exterminating the larger species. In Brixham Cave, Devonshire, flint implements of the chase, comprising arrow and spear heads, axes, and knives, have been found among broken bones of the bear, lion, Irish elk, reindeer, horse, elephant, and rhinoceros. In Kent's Cavern similar conditions were observed; and also in the Gower and other caverns in the Mendip Hills of Somersetshire, and elsewhere. In Scotland and Ireland, similar weapons have been found, but not in conjunction with the bones of their lost mammals. The ruder-fashioned of these implements have been ascribed to an earlier and more savage race than the finely-polished and often artistically chipped arrow-points and other tools, and it is believed that they

Fig. 6.—The Irish Elk, restored (*From a Drawing by C. Berjeau*)

bear the impresses of a gradual transition from the one to the other, the more highly-polished being comparable to the tools now used by the savage races of the Oceanic Islands, and lately by the Red Indians of North America

Of the duration of the Ice Age, and of that immediately following it, and the vacillations of climate which may have characterised the latter, there is no very tangible evidence. That both epochs were of long duration, to allow for the deposition of the enormous accumulations of the *débris* of rocks, there can be no manner of doubt. Again, unreckoned ages must be allowed not only for the migration of the animals, but for the dissemination of the plants necessary for their subsistence, seeing that the land-flora was entirely destroyed excepting possibly a few arctic species that may have survived on the island crags still above the surface of the frozen seas of the Glacial Period.

The evidences just adduced, when read by the light of modern science, seem to establish clearly—(1) The presence during a late geological period of an arctic climate in Britain, during part of which a submergence of the area took place, and the latter was reduced to an archipelago of frozen islands, when nearly the entire fauna and flora disappeared. (2) A subsequent re-elevation of the area, and its union with the Continent of Europe, from which the land was re-stocked by the animals and plants of the latter. (3) The submergence of portions of the area now occupied by the Irish Sea, English Channel, the greater part of the German Ocean, and represented by the present physical features of the British Islands.

Such are a few of the remarkable mammals which lived on British soil during the Post-Glacial Period, and the lessons they seem to teach. But for such relics, and the stone implements of man found in a few instances in conjunction with them, we could have known extremely little of the history of the period of which they are the exponents—a period no doubt extremely remote according to man's methods of computing historical events, but of yesterday as compared with older testimonies of the rocks. At all events, in spite of its imperfections, the subject is a good illustration of the value of a scientific knowledge of living and extinct animals, in elucidating past changes of the earth's surface.

## HOW PLANTS GROW.

By G. Dickie, M.A., M.D., F.R.S., etc.,
*Formerly Professor of Botany in the University of Aberdeen.*

THE common observer has some difficulty in understanding in what way a plant increases in length and thickness. But before trying to explain this, it will be necessary at the outset to state the nature of the materials of which plants consist, and of the way by which they are laid down and connected together. A substance of comparatively simple kind is common to all plants, from the smallest mould or moss to the gigantic trees—*Wellingtonia* or *Sequoia* (Fig. 8)—of California, some of which have reached between 300 and 400 feet or more in height, with a relative girth. The term cell or vesicle is used to designate the material in question. In common language, the term "cell" means a small cavity or hollow place; and a vesicle is a little bladder-like structure, the bounding walls varying in their nature.

The cells of plants in the early and active state are not exactly of the simple kind expressed by the above terms—that is, are not at all times mere empty spaces bounded by a wall, but contain fluid and more solid particles; these even may be present without any harder cell-wall. Of such there are examples among not a few of the simpler or lower forms of the vegetable kingdom. These cells and their several modifications, may be compared to the individual bricks and stones in a building; but the process of dressing and cementing may be said, in the plant, to go on *in situ* so long as life is present.

With the assistance of a pocket magnifying-glass, one may get some idea of the structure in question by examining a piece of the production called rice-paper, which is very incorrectly so named, it being really a kind of transparent paper made by slicing the pith of a plant called *Aralia papyrifera*, a native of China. Other substances may be examined in the same way, such as the pulp of an orange or a piece of pith from the common elder. The accompanying figures (1, 2) give a fair general idea of plant-cells as seen under a microscope; but there are other forms which need not be fully noticed here, such as cotton, which consists of long, thin-walled hairs, which cover the seeds of the cotton-plant (Figs. 3, 4); and flax, which is got from the inner part of the bark of the flax-plant; these and other useful fibres are in reality modifications of cells.

The spherical seems to be the original form, of which there are modifications occasioned by mutual pressure and irregular growth. In dissecting or tearing asunder under a microscope cells which in connection have several sides, and thus relieving the mutual pressure, the many-sided cell has been seen, by its own elasticity, to assume the round, or rather, to speak more correctly, the spherical form.

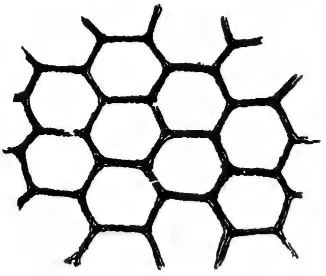
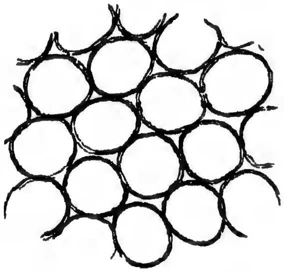


Fig. 1.—Tissue of Pith.

In some of the lower or simpler kinds of plants, the nature of the cell and its reproduction can be conveniently examined. On dripping shady rocks, gelatinous masses of various colours are very common; and at the foot of shaded walls, on the damp soil, red or blood-like patches are also frequent—the latter called by botanists *Palmella cruenta*—that is, "blood-like palmella." A small bit of any such in a little water placed on a slip of glass, and a thinner piece over it, can be conveniently used as an object for examination and study, as illustrative of the structure of the active cell. With simple precautions and arrangements, the said material may be kept alive for some time, and occasional inspection will thus enable the observer to get some interesting information respecting the phases of life in the vegetable cell.



g. 2.—Spherical Cells of Pith.

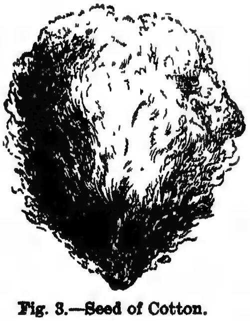


Fig. 3.—Seed of Cotton.

Fig. 4.—Section of Seed of Cotton.

The use of magnifiers for the purposes mentioned will be understood when we consider the sizes of cells. Their diameters vary from a thirtieth of an inch to a six-thousandth part of the same. The first is large and not common; intermediate sizes are frequent; and a minute organism or plant found in France and Germany—*Palmella hyalina*—is reported as having the very small dimension of $\frac{1}{40000}$ of an inch. The cell is capable of producing other cells like itself; and the really active part is not the cell-wall—when such is present—but the softer contents. In order, therefore, to understand the process of growth, it is necessary to know something of the structure of the living and active cells concerned in the process. First, there is an outer covering, the cell-wall, which is more or less elastic, and varying in thickness. In its earlier stages it is soft in texture and freely permeable to water; inside there is a softer, less elastic layer, technically called *primordial utricle* or vesicle. The latter is scarcely membranous like the cell-wall, and is merely the outer film of the softer matter, called *protoplasm*. Under the microscope, the distinction between cell-wall and the contained material is often sufficiently obvious; but the application of some chemicals—such as a weak solution of iodine—renders the features more distinct; the contents shrink from the bounding wall. In the soft protoplasm there is usually present—not invariably—a small globular body, called the *nucleus*, often containing smaller granules called *nucleoli*. The accompanying figure (Fig. 5) will enable the reader to understand these structures and their relative position. Cells also contain granules which are coloured. The most important of these give the green colour to plants; the technical term being chlorophyll or leaf-green (p. 21, Fig. 3). In old cells, pith of elder, rice-paper, &c., the protoplasmic contents and nucleus are wanting, and the contents may consist of clear sap or of air. There is, accordingly, merely a framework of cell-walls, these, therefore, being the more permanent. In function there is an essential difference between the cell-wall and the contents. In other words, young cells and old cells differ in this—the former are in an active condition. The presence of the protoplasm is necessary to the formation of the outer part. Vacant places make their appearance in it, and these contain fluid or cell-sap granules, which can often be seen moving from place to place, proving regular movement or circulation of the fluid contents. This can be seen, under high powers of the microscope, in the hairs of the

common nettle, and in other cases also. The formation of new cells, and the changes they undergo, are essential to growth. The former function begins by a change in the protoplasm,

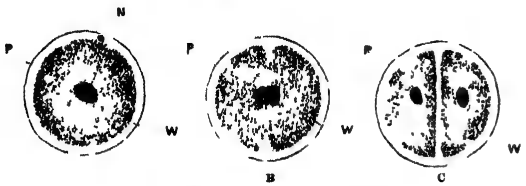



**Fig. 5 —Showing Structure of Cell**
(W) Cell-wall; (P) Protoplasm, (N) Nucleus, (B) Material gradually infolding; (C) infolding complete.

the whole of which, or a part only, may be concerned in the production of such new cells. By division of the protoplasm giving rise to new cells, and the subsequent modifications of such, the mass of the entire plant is built up. Some of the simpler forms of plants already alluded to illustrate very clearly the way in which the protoplasmic contents of a cell give rise to new cells. In certain of these there is a gradual infolding of the soft material at two opposite points, so that finally two (see B and C, Fig. 5) masses are produced. In some cases this process gives rise to four. It is necessary however, to state that in others the whole of the mass escapes from the cell-wall, becoming free, undergoing fresh changes, and finally giving rise to a new being. Figs. B and C illustrate these points.

The water of the cell-sap is of importance in the life of the cell. It is both a solvent and conveyer of nourishment necessary for the growth and the production of new cells.

The formation of a closely-united mass of cells depends on repeated sub-division, already described, and on the development of new walls which separate the individual cells. At first these are thin and soft; the lines of connection are also indistinct; at a more advanced stage, especially where there is considerable thickening of the walls, the line of separation between adjacent cells becomes visible; and this line has been considered by some as a connecting material or cement—called intercellular substance—by which the individual cells are bound together. Fig. 1 illustrates this. The correct view is that there is close union of the adjacent cell-walls, which, however, often becomes modified by unequal growth, so that at certain points the union is destroyed, and a vacancy appears, which may ultimately become filled with air; and doubtless the peculiar star-like cells (Fig. 6) of the pith of a rush depend on this. Of late it has been asserted that cells are not separate, but connected by delicate threads of protoplasm passing through the cell walls, and that many forms of lowly plant life never arrive at the dignity of cell form. But this is still *sub judice*.

The process of growth in the higher forms of plants occasions changes at certain points into fibrous or string-like materials, which give strength and support to the softer parts. This is well seen when a leaf is reduced to the form of a skeleton—the softer parts being removed by maceration in water—a framework of great beauty and variety in different plants (see Fig. 1, p. 20 of this work). By similar treatment of the underground part or stem of some of our larger native ferns, a very beautiful network, with larger and smaller meshes, is revealed (Fig. 7). These parts are called fibro-vascular bundles. In such a bundle of fibres there are admitted two modifications—the one called bast (Fig. 9), the other recognised as wood (Fig. 10); the former being more juicy than the latter, which is harder. In the earlier stages, these vascular bundles are composed of ordinary cells, by the transformation of which they are produced. This change may be complete or incomplete; in the latter case, part of each bundle is capable of further change. In the higher plants, the bast layer is usually on the outside, the woody part being internal; and where transformation is incomplete, the cells which continue in an active state lie between the other two.

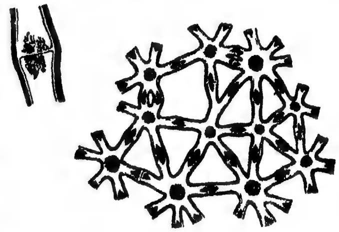


**Fig. 6.—Cells of Pith of Rush.**

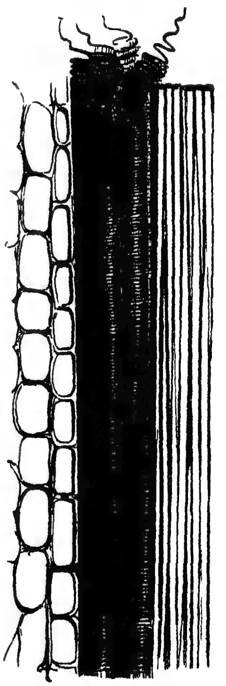


**Fig. 7.—Spiral Vessels between Pith and Woody Fibre.**

Without entering into details, it may be sufficient to state that the parts of a vascular bundle are usually considered as either true vessels (Fig. 11) or fibrous. The former consist of long cells in rows, one over the other; the partitions between the ends partly

or entirely disappear, and thus there are continuous tubes, the most notable of which have a spiral band in the interior, which may be continuous or partly broken up, and the coils closer or wider apart in different cases. Such are easily seen in the fibrous portions of a piece of boiled rhubarb-stalk, and a weak solution of magenta tinges the spiral, the cell-wall remaining almost or entirely colourless. In this way one may procure preparations of great beauty.

The other fibrous portions of a bundle are long, spindle-shaped, and without the spiral band; they often contain grains of starch, and can be seen in thin slices of wood. Those called *parenchyma* cannot in some cases be distinguished from the

Fig. 8.—Wellingtonia (Sequoia) Gigantea of California.

wood-fibres; they are generally more juicy, and with softer walls. They can be seen in the more central parts of a carrot or radish. There are some other modifications which can only be briefly mentioned, such as the branching tubes — called *laticiferous* —which contain either a limpid or milk-like juice, and present an appearance like that of the blood-vessels of animals (Fig. 12). The underground tap-like part of the common dandelion yields very fine examples of such. When carefully washed, it is seen to be covered with a thin, brownish skin, which being gently removed, and then a thin slice taken from the part which it covers, branching tubes can be observed when the preparation is examined with a moderate power of the microscope. These tubes originate from cells, the partitions between which disappear during the process of growth, and hence the tubes become continuous. These are filled with an opaque sap and granular matter.

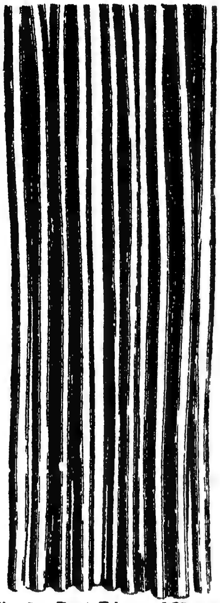


Fig. 9.—Bast Fibres of Hemp. (*Magnified.*)

Certain chemical changes always take place during growth. Water, so necessary for life in the plant, consisting as it does of the two gases oxygen and hydrogen, yields supplies of these, and also the medium by which other matters dissolved in it are conveyed to the plant. The amount of water required for vegetable growth varies greatly in different cases, some plants being adapted to live in dry, arid districts; others requiring external conditions of the opposite kind. Evaporation of water from the surface of a plant determines, as we have already seen (p. 22), supplies of the same taken up by the roots, and transmitted upwards chiefly, though not exclusively, by the woody part of the vascular bundles. Certain colouring matters in solution, to be taken in by the roots, have been employed to demonstrate by what parts the sap ascends. The rapid absorption of water may be shown by a very simple experiment: any common plant with a long stem and successive series of leaves, in a flower-pot, is allowed to droop for want of water; a copious supply of this necessary fluid being then given to the soil about the roots, the leaves from below upward are not long in becoming turgid, resuming their former rigidity. Water, then, is the medium by which certain matters necessary for life and growth are conveyed to the plant. The more important of these are carbon, in the form of carbonic-acid gas (the "choke-damp" of the miner), oxygen, hydrogen, and nitrogen gases. Others are also requisite, as potash, lime, phosphorus, magnesia, silica. The air and the soil are the sources from which plants derive their food; in different soils there is considerable range in the mineral ingredients. The cultivator must attend to this in order to grow profitable crops; and supplies by manuring are required. It may be worthy of notice here that some of the lower forms of plants, especially those growing in water, seem to have the power of selecting special matters. This is very notable in certain minute organisms called *diatoms*, which abound in waters fresh, salt, or brackish, and have a very wide distribution, being found in all parts of the world hitherto explored. These have a coating of silex, and form in some localities extensive deposits, called fossil earths; some of the sea-weeds become gorged with carbonate of lime, forming solid masses which are often mistaken

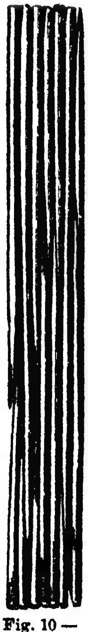


Fig. 10 — Wood Fibres. (*Magnified*).

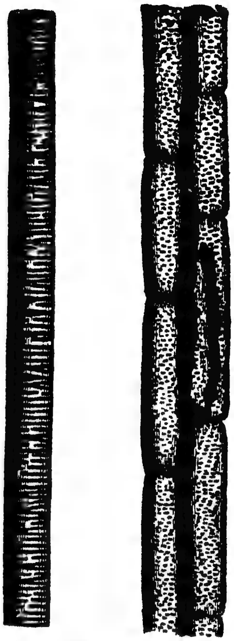


Fig 11 —Barred and Pitted Wood-Vessels. (*Magnified.*)

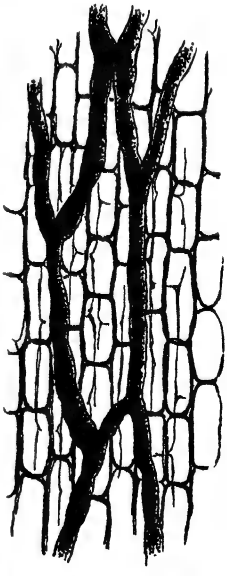


Fig. 12.—Milk-bearing Tubes. (*Magnified.*)

for corals. But several also of the higher plants deposit in their substance mineral matters in quantity. When a rick of straw is burnt down, lumps of impure glass are found among the ashes, the action of heat producing union of the potash and silica which the straw contains. The substance known in India under the name of *tabuchir*, or *tabasheer*, occurs in lumps deposited in the joints of the bamboo; it is mainly composed of siliceous or flinty matter. The pottery-tree of Brazil has some of its tissues full of mineral matter; but hard parts, such as shells of nuts, stones of stone-fruits, &c., owe their character to the very thick walls of the cells. The root, besides being a point of fixture and support, serves an important function as the part by which fluid is chiefly taken in. In order to understand this, it is necessary to state that when two fluids of different densities—*e.g.*, water and syrup—are separated by a thin membrane, whether animal or vegetable, the denser fluid increases in bulk by the passage of the other through the membrane. A simple experiment, which one can easily make, illustrates this. Take, for instance, the bladder of any small animal, half-filled with a solution of sugar, forming a moderately-diluted syrup; secure the opening by a string, and place it in a vessel of water. The bladder, after a time, will become full, and may at last burst: this property of such membranes is technically called *osmose*. If the observer has a microscope, the same result can be seen by dusting a little pollen from a flower into a few drops of water; each grain swells, and finally bursts with some force. Or place them in syrup, instead of water, and the effect is reversed—they shrink. Now the fluid matter in the soil being less dense than that contained in the cells of the root, by the process of *osmose* is taken in, and thus we have the commencing force of circulation or diffusion of sap in the plant.

The food taken in, with some exceptions, consists of substances which have a considerable proportion of oxygen; but the solid materials of the plant formed from these contain much less of that gas. The external conditions necessary for this change will be presently alluded to.

The growth of a plant consists in the formation of cells and increase of their number by the process already described, and is dependent on the presence of substances assimilated or digested from the food-materials; and since these have a composition different from that of the harder and softer matters of the plant, there must therefore be a chemical change going on during growth. But these substances may be a longer or shorter time stored up for the growth of the individual; starch, oils, &c., may be stated as examples, and are of common occurrence. In a potato, for instance, the cells abound in grains of starch, and when the tuber is planted or placed under conditions favourable to growth, the starch is used up in the formation of new cells. Starch in this case is therefore stored up in reserve for future use. And the same is true of other matters, such as sugar, fats, and oils. All these are chiefly concerned in the formation of the cell-wall, and consist of carbon, oxygen, and hydrogen in different proportions. And here it may be remarked that the formation of sugar, or a modification of it, sometimes serves another and important purpose: in many flowers, such as those of the honeysuckle, &c., the presence of a sweet secretion serves to attract insects, which give material aid in fecundation—necessary for the formation of seeds.

There are, however, other products of digestion which yield materials for the formation of the essential part of the cell—the protoplasm, namely, and the green granular colouring matter. These products are technically called *albuminoids*, and differ from the others in containing a proportion of nitrogen stated to be from 15 to 18 per cent., besides carbon, hydrogen, and oxygen, and small proportions of sulphur and phosphorus. When the juice of a plant is heated, part of it coagulates, just as the white of an egg—called albumen—does when treated in the same way; hence the term *albuminoid*—that is, a matter resembling albumen.

Another product of the plant is vegetable *fibrine*, such as forms a large proportion of wheat-flour, and can be got from common dough by washing and kneading in water until nothing remains but a sticky or tenacious residue, which is the substance in question.

There is another called *caseine*, which is the name given to the chief ingredient in common cheese. It is abundant in many seeds such as peas, beans, lentils, and others (and it may be noted in passing that the Chinese prepare from such seeds a vegetable cheese); and if a little vinegar be added to pea-soup the presence of caseine is at once indicated by partial coagulation of the soup.

Besides the substances just mentioned as important in the growth of the plant, the hard parts of the cells are in some cases used up for the same purpose. The hard seeds of the date (Fig. 13), ivory-nut, &c., in germinating, undergo a change, becoming softer, partly dissolved, and thus available for the growth of the young plant. In the case of the

vine, the *glucose* or grape-sugar, and cream of tartar deposited in the leaves pass to the fruit and act as nutrients, hence the care that is required in removing or pinching off the ends of fruit-bearing branches; if the operation is overdone, the fruit deteriorates.

There are certain external conditions necessary to bring about the changes which take place in a living plant—viz., heat and light. The amount of each, it is needless to say, varies in different localities, and plants are adapted in accordance; those peculiar to the warmer regions cannot be expected to succeed in cold climates, and the temperature which suits them would not in every case permit the existence of many species which grow in colder zones.

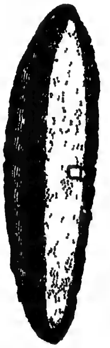


Fig 13.—Section of a Seed of Date.

The substance of plants is a bad conductor of heat. A very simple experiment proves this. A wire of metal will transmit heat from one end to the other more rapidly than a strip of wood of the same dimensions, and, *vice versâ*, the metal cools faster than the wood. Some notion of all this is requisite for the proper treatment of plants in glass-houses.

The influence of temperature is seen in the movements of the green grains—chlorophyll. In winter it has been observed that these collect in masses in the middle of each cell, and when the heat increases, they resume a position on the walls of the cells.

The stimulus of light on the green contents of leaves is necessary for the formation of new products and the storing up of these in the plant; when a full supply of such is deposited in the cells, there is less necessity for the action of light. This is illustrated in the germination of seeds, and the growth of stems and leaves from bulbs and other underground organs. The presence or absence of light has also an influence on the movements of the grains of chlorophyll: in darkness more or less complete, these collect on the side wall of the cells, and when light is admitted they return to the walls of the cells parallel to the surface of the organ. In all cases, whether heat or light, or both together, act as stimuli, the green grains move from one position to another, not because they have any self-power of motion, but are so carried by the more fluid contents.

The food-materials, which have been already alluded to, for the most part contain a good proportion of oxygen. The cells and their modifications contain little of this element; it is therefore a natural conclusion that in the course of growth there must be a loss of oxygen. The chief and necessary agent in this is light. White light is a combination of rays of different colours. It is a point of some interest to determine the different influences exercised by these, since the stimulus of light on a green plant gives rise to the emission of oxygen gas (p. 21). By a very simple and beautiful series of observations, Professor Sachs has noted the amount given out by a water-plant—*Elodea Canadensis*, now much too plentiful in some parts of Britain—under the influence of different coloured rays. Taking yellow light as the standard and most influential, and calling it 100, we have the following result:—

| | | | |
|---|---|---|---|
| Red | 25·4 | Green | 37·2 |
| Orange | 63 0 | Blue | 22 1 |
| Yellow | 100·0 | Indigo | 13·5 |
| Violet | 7·1 | | |

The brightest rays of the spectrum, therefore, act as chief agents in producing the evolution of oxygen; the yellow rays and those adjacent have the strongest influence. The process so well known to cultivators, called *blanching*, by growing celery, rhubarb, &c., in the dark, shows very well the importance of light as an agent in the growth and health of plants. The action of light on the green grains of chlorophyll gives rise, as we have seen, to the escape of oxygen from the plant, thus contributing to the purity of the air, and supplying a material necessary in the respiration of animals. The presence of water-plants, such is the *Vallisneria spiralis* (Fig. 14), in an aquarium aids in preserving the life of animals in it, obviating the necessity for the frequent entire change of the water, supplies of such to make up for loss by evaporation being mostly sufficient. These supplies, containing a proportion of carbonic-acid gas in solution, thus yield carbon, &c., for the growth of the plant. The latter in turn gives out oxygen for the animal respiration.

It is a trite remark, long in use, that in coal and wood the sun's heat is stored up, to be given out during combustion; and it may even be conjectured that the different colours which make up white light are also thus stored, since all those beautiful and valuable colours, magenta and others, are produced from one of the products of that unsavoury material known under the name of coal-tar. In reference to this we may quote Dr. Odling's statement in a lecture at the Royal Institution in 1869:—"If the sun, instead of shining on the plants which grow on the earth's surface, were to shine entirely on the stones, it would heat the air much more than

it does. As it is, a portion of the heat disappears, being absorbed by the vegetation. The amount of heat taken in by a growing piece of wood in unburning the carbonic acid of the air into carbon and oxygen, is exactly equal to that which it gives out

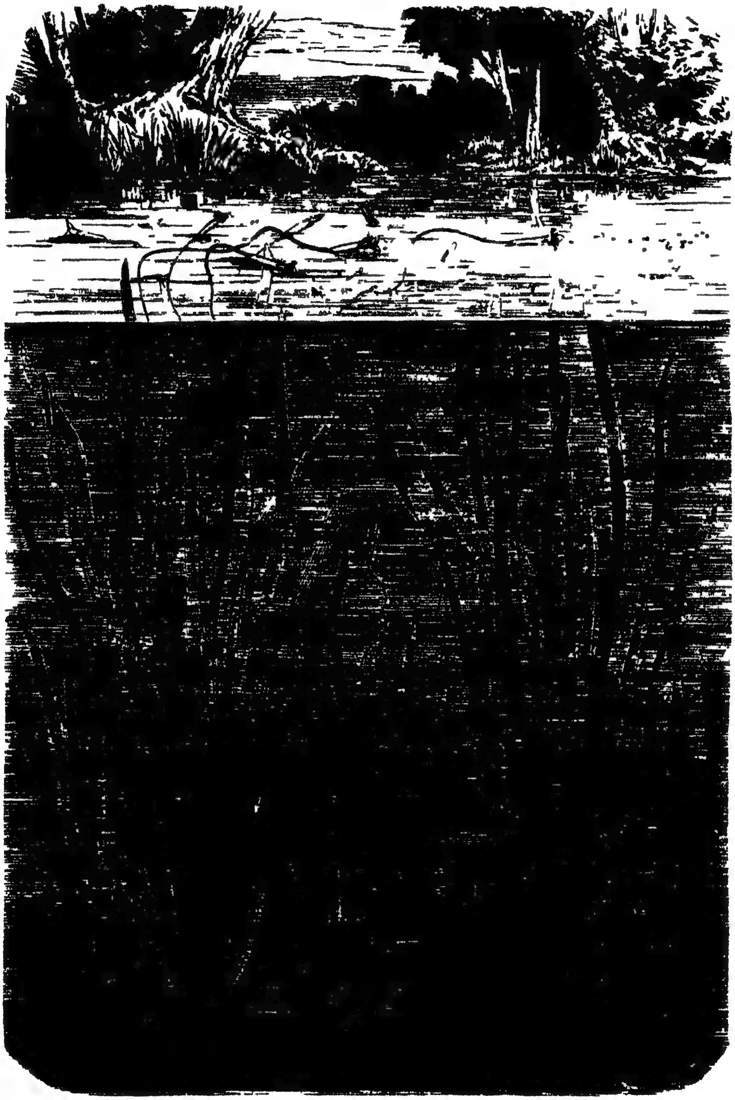


Fig 14—Vallisneria Spiralis

when its carbon is reburned in the air; accordingly, when we burn coals or peat, or consume bread and oil in our bodies, we are really manifesting once more, in the form of heat, the sun's rays which years and years before shone on the plants from which those substances are derived." More might be said on the influence exercised by light; for example, its action on plants whose leaves are sensitive, such as *Mimosa pudica* (the sensitive plant) and others of the same genus, also species of *Oxalis*, *Marsilea*, &c. In such cases the blue and violet rays of light are stated to be the chief stimuli.

To sum up, plants grow under the influence of certain necessary external conditions—light, heat, and moisture—which, acting as stimulants, enable the plant to produce new products from carbon, oxygen, hydrogen, nitrogen, and various mineral matters taken in by the roots, and in some cases by other parts as well. Evaporation of water from

the leaves, &c., determines the absorption of fluid by the roots, and its subsequent diffusion throughout the tissues of the plant by osmose; the green organs give out oxygen gas in considerable quantity under the influence of light; new cells are formed by division of the protoplasm, and some of these subsequently undergo modifications of form and structure. The new products stored are in turn used in building up the different organs.

The growth of a plant and its different parts is owing to the repeated production of new cells, but the rate of increase varies greatly in different cases and at different ages—at first the increase is slow, but subsequently becomes more rapid, and at a later period again slow.

The varying rapidity of growth in different plants is too well known to common observers to require any extended notice here; a few examples may suffice. A plant now not uncommon in gardens, *Heracleum giganteum*, a native of Siberia, is a biennial; early in March its young stem and leaves begin to appear above ground; toward the end of July, or earlier, according to locality, the plant may attain a height of twelve or more feet, with numerous very large leaves, and a huge *umbel* or truss of flowers which rapidly yields abundance of seed.

The rate of growth of certain trees is a subject of much interest and importance in forestry. We may confine any remarks to a few of our common trees. A cross cut near the ground, at the base of the stem, shows a central spot—the pith—and, arranged concentrically, a number of layers, called the "annual zones," marking the growth of each season, the whole bounded externally by the bark, of greater or less thickness.

A careful inspection of cut stumps, counting of the annual layers, and measurement of diameter and circumference, will often yield very interesting results regarding age and rate of growth in different years. By ascertaining the exact date on which a tree was cut, each annual layer may be referred to the year of its development, and a summary of all can be carried off by simply applying a strip of writing-paper from the outer margin of the pith to the outer edge of the layer next the bark, and then with a pencil making a mark on the paper opposite the margin of each zone.

In some cases, such as the oak (Fig. 15), the annual layers are rather uniform and of moderate thickness, the rate of growth being slow. In the ash they are generally of considerable breadth, indicating quick growth; but this is liable to vary according to the character of the season—in cold, ungenial summers the rate is less than in those of an opposite kind. And here we may give a very notable example, observed some years ago when collecting materials for a paper on the Forest Trees of Aberdeenshire. In the interior of the county, a number of ash-stumps, all at the same place, were found to have one hundred and eleven zones; the trees had been

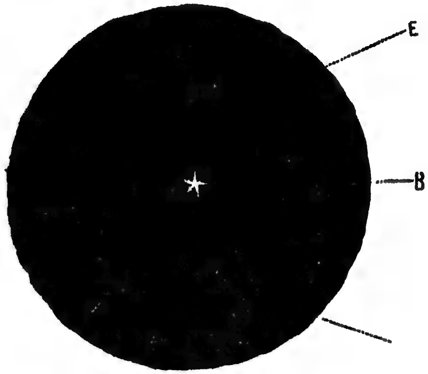



**Fig. 15.—Vertical Section of Oak of 18 years' growth.** (A) Sapwood; (B) Heartwood; (E) Bark.

cut down—near the root—in 1838. On counting back from the external annual layer, it was observed that two of the zones, very much thinner than the others, corresponded to the years 1781 and 1782. On making inquiry of some aged persons, it was stated that 1781 was notable for its cold, ungenial summer, that 1782 was still worse, and, in fact, a year of famine in the North-east of Scotland; even in October of that year the harvest was scarcely begun; severe frosts and heavy falls of snow destroyed the standing corn, a large proportion of which remained uncut at the end of December. Here two ungenial years were permanently recorded in the heart of old trees.

The larch, like the ash, has generally well-developed layers, indicating comparatively quick growth. In cross sections of the Scotch fir, when of the age of 70 years and more, the general character is uniform and fair thickness of the zones, up to 60 years or thereby, after which they are thinner and thinner as age advances.

In cross sections of pines from the north-eastern parts of Scandinavia, there is often rather uniform thinness of the layers; and in a very old stem from that quarter, they were so thin and numerous that we found it very difficult to count them—in other words, to get an approach to the probable age of such a stem. As a consequence of growth, we often observe a change of colour in the wood, as in the common laburnum, the zones near the centre being darkest in colour.

In all cases, the external or youngest layers are the most juicy and least dense, and every carpenter knows the difference between sap-wood and heart-wood.

In this way plants grow. But how the flint of the soil is transferred into the substance of the plant, or in what manner that which gives no nourishment is transformed into what is good for man and beast, is a question which requires the aid of chemistry in its explanation; and even then the certainties bear a disproportionate ratio tc the doubts.

# LAKES, AND HOW THEY HAVE BEEN FORMED.

By Professor P. Martin Duncan, M.B. Lond., F.R.S.

LAKES add greatly to the charms of mountain scenery; they often relieve the monotony of the country through which great rivers are flowing, and in some instances their vast extent brings, as it were, the waste of waters within the land. Stupendous as may be the precipices, and awful as may be the gloom of the deep gorges of some mountain chains, the absence of the broad silvery streak of the lake, renders their influence on the mind much less impressive than when the rugged lines of peak and pass are relieved by the reflection of their outlines and shadows from the horizontal mirror of the land-locked water. The lake gives the high light to the dull colour of the hills, and its ripples and waves animate their quiet grandeur. Often when hidden amongst lofty mountains, the lakes look dark and solemn indeed; but even then they give an expression of altitude and solidity to the surrounding hills, and render the appearance of the nearly vertical rocks, whose feet are washed by them, all the more steep and imposing.

The plains and low hills which border on many mountain chains, relieve the eye, tired with the irregular outlines that reach far up towards the clouds; but when a lake is in their place, it entrances the mind, and obviates the sensation of monotony. The great lakes of the world are as seas to the inhabitants of their shores, for the land is not visible on the opposite side; and those who sail on them, have as many stories to tell about their dangers and marvellous doings, as the true salt-water sailor has of the ocean. Some lakes are profoundly deep, are often agitated without the action of the wind; and all which are in the neighbourhood of high mountains are subject to sudden and dangerous squalls.

On looking at a map of the world, it will be noticed that some lakes are situated without much order or relation to the mountains of the continents, whilst others crowd the path of the streams running from them to the sea. The largest lakes in Europe (the Euxine being called a sea) are far to the north, and those in the districts east and south of St. Petersburg and in Finland are large and uninteresting. Further north, there are great lakes in Lapland; and others—not mere swamps and pieces of water bounded by flat land—are found along the course of the rapid rivers running through Sweden, from the Scandinavian mountains. A large lake is in Hungary—the Lake Balaton. In Bavaria, south of Munich, there are many considerable lakes along the course of streams; none, however, are so large as that of Constance, in Switzerland; whose other great lakes are these of the Four Cantons, besides those of Neuchatel and Geneva; while smaller ones are Lakes Thun and Zug. On the south side of the Alps, the large lakes are those called Maggiore, Como, and Garda. Our own beautiful lakes of Cumberland, Westmoreland, and of Scotland (Fig. 2) and Ireland, are small in comparison with those just noticed; and their size is equalled by many others in Switzerland, Italy, and in Austria about Salzburg and in Carinthia. France and Spain have no lakes of any importance; but there are many small ones in Greece and Western Turkey.

The Caspian is a vast lake, to all intents and purposes, and so is the so-called Sea of Aral. The other Asiatic lakes of importance, from their size, are the Lake Van and Lake Urumiyeh, in Kurdistan; Lakes Balkash, Kosgol, and Baikal (Fig. 3), to the north; and several in Tibet, and to the north-east of the Himalayas. In Africa there are the now familiar great lakes of the equatorial portion to the west (Fig. 5), and Lake Tchad in Central Africa; but there are none of any great importance in Australia, except Lake Torrens. North America, with its great lakes of Erie, Ontario, Michigan, Huron, Superior, and Champlain, has many others to their north and some to the south (Fig. 4); and there is the celebrated Great Salt Lake in Utah

Fig 1.—Lake Titicaca, South America

in the west. Lake Nicaragua is important in the Isthmus, and the extraordinary Lake Titicaca (Fig. 1), in South America, is the only one there of any importance, and it is small. Numerous very small lochs, tarns, and other pieces of water, whose extent is very limited, but whose depth may be great, are not placed upon ordinary maps, but they are found in and about almost every mountain range. Nevertheless, they are more frequent in the northern regions of America and Europe than anywhere else. Swamps cannot be considered as true lakes, but they often surround them, and it is extremely probable that many were once worthy of the name, and that they have since been filled up. If the pieces of water which are connected with swamps, and into which streams flow, are to be considered lakes, the number of them must be very considerable in some parts of the world; but, on the other hand, vast districts are without them. The salt-water lakes which have no direct communication with the seas are very remarkable, and they are suggestive of the origin of many large lakes; and equally interesting are the small, pond-like tarns surrounded by hills, and cut, as it were, like basins out of the rocks, whose pure, cold, fresh water is the home of fish whose ancestors lived in the sea. The *lagoon* is rather a piece of seaboard cut off by *débris* or coral growth from the surrounding ocean; but it may be the first stage of a lake, should the land be upheaved beyond the level and influence of the sea. Sometimes, in countries where the glaciers fill up the upper valleys, their streams are dammed up by a glacier crossing their path. Then a glacier lake is formed, which may be destroyed on the giving way of the barrier of ice. Lastly, in Australia, or regions where water is scarce enough, sometimes there are

small circular lakes, resembling others in Europe not far from the banks of the Rhine, and in Central Italy. Similar circular lakes are found in Oregon, and in the Equatorial Andes; and they are the sunken craters of volcanoes filled with water. Whilst some lakes have no outlet for their water, and yet receive the water-drainage of the hydrographical basin in which they are placed directly, or through the medium of the stream that runs into them; others have streams issuing from them, and running seawards. Hence lakes may be divided into many heads—from their size, position, from the nature of the water, and from their having, or not having, streams to carry their water away, but best of all from their manner of formation. Almost all the great rivers are connected with small or great lakes somewhere or other during their course, but the rule is not invariable, and some of the lakes whence some rivers appear to arise may be very small. The great African rivers, the Rhine, Rhône, and Danube; and some of the Russian rivers of Europe; and the Fraser, Mackenzie, and Columbia, in North America, and the St Lawrence of the same continent, with its numerous branches, are instances of streams rising from lakes of different sizes, or of rivers passing through lakes on their way to the sea. On the other hand, a glance at a map will show that many important rivers never have to do with lakes at all, and that some flow into lakes which have no outlet to the sea.

Lakes may, or may not, then, form part of river systems, and some play the part of the sea to their rivers. Some are situated far above the level of the sea in relation with the mountain systems and the origin of rivers, and others are found but little above sea-level.

The depth of many lakes is great, and, in the case of some, which are high above the sea, their floor is really below sea-level. Others are not so deep, or their great altitude only permits of their bottoms being far below the surface of the land, but still higher than that of the sea-level. Usually these pieces of water are surrounded by and rest in hollows in rocks of great geological age, whose hardness and impermeable nature prevents the water escaping by downward drainage, but some are in the hollows caused by volcanic eruptions, or

Fig 2.—Loch Leven, Scotland

by the sinking down of volcanic cones into the earth. The smaller lochs and tarns are sometimes called rock-basins, from their giving the impression of having been sculptured out of the rock by natural agencies; and, indeed, sinking in, cracking of the earth, and wearing of hollows by the so-called "agents of denudation" and volcanic action, have had to do with the origin and progress of all lakes at some time or other of their existence.

The highest lake of any considerable size is Lake Titicaca, in South America. It is situated about 100 miles to the north of Arica, on the western coast, and it is 12,800 feet above the sea in the midst of a very great breadth of high ground. It is 924 feet in its greatest depth. Many parts of it are shallow, especially towards the shores; there are islands in it, and the surface covers an extent of some 4,600 square miles. The lake receives numerous streams at its northern extremity, but the eastern and western water-sheds are low ridges, distant twenty or thirty miles, and their waters are intercepted before they reach the lake. A river issues from the south-western part of the lake, but it is a small stream which runs southward, and it terminates, in about 180 miles, in another piece of water, called Lago del Desaguadero. Now the Lake Titicaca contains some kinds of animals of the class *Crustacea* (that to which crabs and lobsters belong), which are known in fresh water in many parts of America; and one of them is found in Peru at a lower elevation of 3,300 feet, and also at Puerto Bueno, in the Straits of Magellan. It is, in fact, a marine crustacean which now lives in fresh water in Lake Titicaca, many thousands of feet above the sea, and there is no connection between the lake and the sea. There are many other proofs that the district which contains this lake was, not very long since, geologically speaking, near the level of the sea; and some which, in combination with the occurrence of a sea crustacean in the fresh water, tend to prove that, still earlier, the lake was a deep cavity on the ocean floor. A small lake called Siri-Kol, at the origin of the Amoo (the modern name for the Oxus), is still higher than Lake Titicaca, while the "Sacred Lakes" of Tibet are 14,965 feet above the sea.

A great lake, which is about as large as the half of Scotland, lies amongst the steep mountains which skirt the high table-land of Central Asia to the north: it is Lake Baikal, and is in the midst of a catchment-basin (p. 209), which extends beyond the shores in some places for a considerable number of miles, and in others comes precipitously to the very brink. About 1,800 feet above the level of the sea, it is about 400 miles long, and the mean breadth is between thirty and forty miles. It is very deep, and at the northern end the depth is 1,373 feet, and it is said that in some places it reaches 800 fathoms deep. It has a bottom of pebbles, clay, rock, and sand, and was once much more extensive than it is now. Great rivers enter into it, one having a previous course of 300 miles, another of 450, and a third of 700 miles, and they drain a land-surface equal to the United Kingdom in size. Possibly 160 small streams and rivers also flow into the lake. On the other hand, only one stream—the rapid Lower Angara—carries off any of the vast quantity of water poured in, and it cannot possibly remove more than one tenth part. Situated at least 1,200 miles from the sea, with which it has no connection by river, and from which it is separated by mountains 3,000 feet in height, besides enormous plains, the lake, full of fresh water, does not overflow, in spite of the constant increase of influx of water over the outgoing. It contains amongst its very rich natural history many fishes and other animals which live in the sea elsewhere: sturgeon, salmon, and a species of seal which lives in the northern seas, are common. The climate is severe around the lake. The summer there is short, and snow falls at the latest in September; a thick, cold fog covers the lake for days in the months of July and August. As in other instances of land-locked lakes well supplied with water, and out of which but a fractional part is carried by the stream, evaporation from the surface must account for its not overflowing. But it is extremely probable that there are underground cracks in which small rivers flow at a great depth. Nevertheless, the occurrence of the sea-living fish, and the seal, infers, as in the case of Lake Titicaca, the former existence of this great inland sea as a cavity in the ocean floor. In the geological age when extreme cold prevailed over high latitudes in Europe, Asia, and America, sea-borne ice drifted far south over the land; and ever since the expiration of that period, those formerly submerged tracts have been gradually elevated, the process being still in operation in some places. This was the time when Lake Baikal was uplifted with the surrounding continent, and seals and salmon could not escape, but have multiplied there ever since. The country around the lake suffers from earthquakes, and there are hot and sulphurous springs in the neighbourhood. Moreover, geologists have detected proofs that volcanic phenomena have been comparatively

lately in action there. There are islands in the lake which stand out of deep water, and, as will be shown on another occasion, they testify to a former state of things which preceded the continental system of Northern Asia.

On looking at a good map of Central Asia, it will be noticed that Lake Baikal has several small lakes trending at some distance from its north-east corner to the south and east; and then Lakes Ebi-nor and Pei-lu, follow to the east. Again, to the north-east of the great lake, there are several arranged in a line or series. On the southern boundaries of the lake, there are terraces on the sides of the hills one over the other, and they indicate that the body of water once beat upon them, they being relics of the beaches of the lake when it was broader and higher. Again, the western side of the lake is bounded by perpendicular cliffs which come down to the water's edge: they are undermined by the waves, and are broken down and ruined, after the manner of cliffs by the sea-side, and year after year the lake encroaches on them and extends. It is stated that the temperature of the water does not follow the rule, and get colder with depth, but that it is slightly warmer in some places where very deep. Possibly hot springs may flow in here and there, especially as the whole neighbourhood is subject to earthquake, and contains abundant evidence of not very remote volcanic action having been manifest. In the history of this remarkable lake, there appear to have been several phases. First, the bed of the lake was formed (and how does not exactly seem capable of proof as yet); then it was filled with the wash-down of the rivers that poured into it. Secondly, this alluvium was washed out, and water occupied its place. And, lastly, the waters on the whole have retreated, leaving the relics of the old alluvium upon the terraces. The numerous other lakes around, some of which contain the remarkable marine animals in their fresh water, formed once a number of depressions in the broad sea which flowed far above the floor of Lake Baikal. The land rose, and these pieces of water and the great lake were left like so many pools after a flood.*

The great lakes of Canada and the United States are in the course of the river St. Lawrence; and if its catchment-basin be considered to cover 537,000 square miles, they occupy at least 149,000 square miles of it. The first, or the lake which forms the source of the water of the great river, is called Superior, and is more than 400 miles long, its extreme breadth being 175 miles, covering a surface nearly as large as England (about 7,000 square miles short); it is a great inland fresh-water sea. Not situated at the altitude of Lake Baikal, it is still quite as interesting, for although its surface is only 627 feet above tide-mark in the Atlantic, its floor is positively lower than sea-level by some 160 feet or more. Probably this vast lake is larger than the great Victoria N'yanza of Eastern Africa, and surpasses all others, which have fresh water, in size. The structure of the country around is remarkable, for it would appear that the surface of the earth must have been exposed to many changes of level there. Far back in the history of the globe there were volcanic eruptions there; and the rocks, worn down and altered, remain to the present, to testify to the action of forces which produce elevation and sinking of the land. The oldest known hills and layers of earth bound the lake to the north, and a line runs along them, more or less from east to west, denoting that whilst the country was land, and motionless to the north of it, the southern districts were the seat of repeated surgings when they collected the sediments washed down from the land and carried off by the rivers of the day. Hard, steady rock was and is as it were the neighbour of softer, and this latter has been subjected to movement. Long afterwards the erosion or wearing out of the softer earth began, and it may have proceeded for ages. It is certain that the sea once filled the lake, for the descendants of the sea animals are found in it, as in Lake Baikal; and like that lake, the salt of the water has long since gone. The waters of Lake Superior flow into the great body of water in the shape of a bold bend which forms Lakes Michigan and Huron. The latter is connected by a small river with Lake Erie, and this with Lake Ontario, whose surplus flows over Niagara Falls into the river St. Lawrence.

Further to the east and to the south of this river is Lake Champlain. An examination of this small lake explains the general condition of this side of North America just before the present state of things commenced. There are terraces around the lake, of earth, containing shells, they being the relics of the old shores, at a height of 468 feet. This Lake Champlain, then, formed once a depression on the sea-floor. The sea reached all over the State of Maine, and up in Canada to the borders of Lake Ontario, for the terraces or old sea-beaches are 500 feet high above water-mark at Montreal, and they contain sea-shells. Further to the north the shells and old beaches are 1,000 feet

* From Notes by Professor John Milne, F.G.S.

above sea-level. Thus an arm of the old Atlantic came far inland, and a vast district was under the sea. When uplifted to form the present land, the great river-valley and Lake Champlain became a trough and a great pool respectively. Great lakes exist to the north-west of Lake Superior, such as Lake Winnipeg, and the Bear and Slave Lakes; and on a globe the whole of this great series of lakes forms a curve indicating the direction of the upheaving force which produced their present position.

Fig. 3.—Lake Baikal.

The discovery of the great lakes of Africa in the east of the continent, and in the neighbourhood and south of the equator, has been followed by their being roughly surveyed, under stupendous difficulties. When their depths and the nature of their fish and smaller animals, and the nature of the geology of the surrounding country, shall have been settled, their interest to us may possibly be greater than that of any other inland sea; for such they are. Vast masses of fresh water, situated high above sea-level—some communicating, others not—and belonging to two or three systems of land-drainage, they are as yet full of mystery. The Albert N'yanza is 2,720 feet above sea-level, and its northern outlet leads to the Nile. It is connected, by means of a river and small lake, with the great Victoria N'yanza to the south-east. This lake, but slightly smaller than Lake Superior, in North America, is no less than 4,168 feet above sea-level, and is 21,500 square miles in area. On the west of the southern half of Victoria N'yanza is a lake with considerable north and south length, but it belongs to another water-system, and the two lakes do not communicate. This is the Alexandra N'yanza. Lake Tanganyika is a vast lake, narrow, but seven degrees of latitude in length, and 2,746 feet above sea-level. It forms one of the group, and is to the south-west of the great lake, and south of the Alexandra N'yanza. These lakes are on an elevated table-land, from which rise up mountains

which are their water-sheds; and the rains, carried down their flanks by streams, flow into the lakes. Probably there are three sets of mountains which separate the lakes, as just stated; and all travellers who have visited those remote regions refer to evidences of volcanic action in the country. The lowest lakes are to the east of Tanganyika, and one of two small ones (Kassali) has an altitude of 1,750 feet.

Towards the south, the elevated table land system is lower, and in its midst, at the height of 1,300 feet, is Lake N'yassa. It is separated from the other lakes by hills, and is to the south-east. It will have been observed that, whilst the great lake-systems of North America, comprising Lake Superior and those between it and the River St. Lawrence, and the African lakes just noticed, originate rivers of imposing size, Lake Baikal has no river that flows to the sea from it. The climate of Lake Superior and Lake Baikal is much the same, that of the Asiatic lake being more genial than the other; but the heat of the African lake-district is great, and the seasons do not change much. The aspect of the country and of the vegetation differs in the three regions, and the forests of the northern districts—so monotonous from the preponderance of trees of the fir tribe—are singularly unlike those of the tropics, where vegetation runs riot, and large-leaved trees are the rule. The rainfall is probably greater in the African lake-district than in the others, but it is compensated for, by the rapid and constant loss of the lake's water by evaporation. It is evaporation, to a certain extent, that keeps the greater lakes from overflowing, for their outflowing rivers carry off a very small proportion of the water that falls every year. The northern lakes freeze during many months, and the rain is converted into snow before it falls during the winter; but still it is difficult to account for the waters of Lake Baikal not accumulating.

Fig 4.—Saratoga Lake, North America.

A lake in Hungary has had much attention paid to it of late, because its general geography is not to be accounted for by one of the theories of the manner in which lakes have been formed. It is called the Platten See, or Lake Balaton, and is 80 miles long, 3 to 10 miles broad, and extends over 420 square miles, being shallow, or only having the

depth of from 30 to 40 feet. There is no visible outlet to the water, and several streams flow in. The lake does not occupy a valley amongst mountains, but it is environed by hills which are at some distance in relation to some parts of the lake, and some bold spurs of others come down to the water's edge. It is a true depression in the earth, and has muddy flats on its sides, and there are some raised terraces or beaches on the hill-sides, testifying to its former greater extension and depth. A peninsula juts into the lake, and is the seat of a volcanic cone; this was once an island in the lake. The shape of the lake is unlike that of those which are evidently formed within the craters or basin-shaped cavities at the top of worn-out volcanoes; but equally irregularly shaped lakes have been formed more or less directly in connection with volcanoes. Besides those already mentioned, Lake Neagh, in Ireland, and Lake Tiberias, and the Dead Sea, are probably situated where there has been depression of portions of the land after volcanic action has ceased. (*Professor Judd.*)

Some great chains of mountains have lakes along their flanks, and in the former history of the globe this appears to have occurred also. The lakes of Geneva, Neuchatel, Bienne, and Constance to the north, and the Lago Maggiore and Lake of Como to the south, are instances. The country is very broken in their neighbourhood, and their profound depths denote breaking and curving of the layers of earth or strata. Huge lakes occupied somewhat similar positions near the main hills formerly, but they became filled up with the rolled stones of the mountains, and now are recognised as important strata of the so-called Tertiary Age.

Some lakes have been surveyed after the manner in which the floor of the deep sea has been lately treated. Not only has their depth been ascertained, for the temperature of the water near and at the bottom has also been compared with that of the surface water, and the substances on their floor have been dredged up and examined. The Swiss lakes have especially been examined, and it has been shown that their great depths have a constant temperature of from 40° to 46° Fahr. The surface-water is warm during the summer, and does not freeze in the winter. The dredge brings up stones near the sides, but elsewhere and in the depths an excessively fine mud without a stone—a mud that takes days to settle down in a tumbler after it is disturbed. Down in those profound and cold depths the rate of motion of the water is extremely small; what current there is, and the waves, are at the surface, and therefore those lakes are not wearing out their floors and making themselves deeper. On the contrary, they are slowly filling up with the fine sediment brought down by the streams from the glaciers. Another and older proof that these lakes are filling up slowly is that deltas are accumulating where the main stream enters them. The bottom of the river Rhône, for instance, is not many yards deep where it flows into the Lake of Geneva, which is very deep, and there is not much current to carry the mud brought down well into the lake. Directly the rapid water of the river, charged as it is with mud, falls into the tranquil lake, its velocity diminishes, and a corresponding quantity of mud falls gradually. This clings to the edge of the lake, and forms a mound under water, and after years, it comes up so close to the surface that land is formed. Along this new land the river branches, before passing to the lake. Whilst the lakes have been slowly filling up, their quantity of water has also been diminishing, for the remains of the old lake-shores are found in some places some considerable distance from the present ones, which are lower. By no possibility can a shallow river falling into a deep lake excavate its floor. The dredgings of the Lake of Geneva prove that living things exist in the dark, cold, muddy depths. Some blind crustaceans live there, and others that have eyes also; and some of the fish of the lake, together with these animals, denote that once there was a connection between it and the sea, probably through a river without great cascades. This same conclusion holds good for all the great lakes that have the descendants of marine animals in them; and therefore these vast pieces of water occupying great depressions or centres in the land existed, when the physical geography of their regions was altogether different. Many small lakes in the northern parts of Europe, Asia, and America contain species or kinds of salmon and crustaceans that have descended from those which once came into the lake from the sea. Either the lake must have had a river reaching the sea, up and down which they may have travelled, or it must have once formed a depression like the larger lakes on the sea-floor. The species sometimes are the same as live in the distant seas; and in most instances some trivial change has occurred in ornament or shape, whilst the creatures have got used to water which has become less salt and finally fresh. All the accumulating knowledge of late years on this subject has gone to prove that great lakes were originally salt, then brackish, and finally altogether fresh in

their water; and the presence of the living things in them proves that they have not been filled up with solid matter since the times of the salt water. Upheaved during the slow formation of mountain chains and of continents, the old sea-floor depressions are now land-lakes, hundreds and even thousands of feet above their former level. Lakes are therefore not things of a few years' duration: the majority are of vast antiquity, irrespectively of the comparatively late time during which they were lifted out of and beyond sea-range. In examining the geology of some countries, the filled-up hollows, and even vast extents of former lakes, can be made out. The nature of the hard rock which was their floor, and that of the fine clay and sand which gradually filled them up, has frequently been the object of study. Some of the old lakes have evidently silted up, and gradually dried their salt; for many of them which were saline, formed rock-salt as they dried up; and sulphate of lime also crystallised and formed layers of gypsum. Even the footmarks of the animals that lived in these shallow waters, and which waddled on to the shore, have been preserved, and the clays and mud are often found to be crammed with minute shell-fish. Other great lakes, placed at a great altitude and near vast mountain-chains, as in the western territories of the United States of America, burst their boundaries, and the water flowing over the land and down streams, excavated these outlets and carried away their floors time after time, until profound ravines and cañons were produced (p. 214). Then the lakes were drained off, and a flat country remained—the old lake-floor—surrounded by hills with terraces or beaches on them, one over the other—the old sides to the lake. The natural end of lakes is thus to fill up or to burst, and their floors to become dry. This is assisted by changes in the rainfall of the region; and it will be evident, if the matter is thought out, that as the waters of the great lakes in the neighbourhood of mountains diminish, the evaporation from them will do so. Hence clouds and mist will diminish in the mountains close by, the rain will be less, and so will the snow. The lakes give the rain which re-supplies them, and the snow which comes back as running water or ice. Formerly the American mountains near the great used-up lakes in the Western Territories had a considerable rainfall, which came from this lake evaporation; but now the lakes are gone, and the rainfall is small in comparison. Sometimes an untimely end comes to lakes by molten rock or lava being poured into them from volcanoes. Thus, in Hindustan there were lakes in abundance, in what is now the Deccan, or the high land from the coast-line of Bombay to the east, and extending north and south. They had clay floors resting on hard rock, plants lived on the floor, and fish, frogs, and myriads of fresh-water snails existed. After awhile, volcanic eruptions took place, and molten rock poured into the lakes, filled them up, killed everything, and baked the clay bottoms with heat, altering the clay and the hard parts of the shells chemically. These lake-remains exist one over the other, in that region.

But although it is not difficult to account for the ending of a lake, it is frequently very much so to frame a theory to account for the formation of the original depression in the earth which formed the floor and sides, and which, often profound in depth, permitted the water to rest as in a basin. How, for instance, was the original great trough in the earth called Lake Baikal formed, or how was that of the Lake of Geneva produced? or the great broad hole of Lake Superior and Victoria N'yanza made? It has been assumed, from the nature of the assemblages of living things—the fauna of some of the great lakes—that they once were on the floor of the sea; and probably this will be hereafter found to be true for the great lakes whose animals have not yet been examined carefully. But it is now known, thanks to the dredging expeditions of many countries which have examined the floors of the great oceans, that the deep sea is very motionless at the bottom, and that it collects substances on its floor, and does not erode or scour it. There are some very deep holes in the ocean, and indeed the greatest depths in the Atlantic and in the Pacific Oceans are circumscribed holes with shallow water around them. But these holes are being filled up; for the dredge brought clay from off their floors, which is the result of the collecting together of earth, shells, and minerals, which have sunk down through the miles of water between their bottoms and the surface. Were the ocean floor to be turned into land, these deep places would be the great lakes of the future. Still, it will be observed that the cause of the depression or hole is not explained.

It has been stated that sometimes lakes have been formed by valleys, in mountains along which rivers ran, becoming blocked up. But how was the original valley formed? for it forms the sides and floor of the lake. That question is easily answered by reference to the theory of the wearing out of valleys from the mass of the mountains by

atmospheric agencies, frost, running water, and, to a certain extent, by ice. The earth-sculpturing occurred first of all; then, during one of the many great movements of the crust, upheaval took place in the course of a valley, and the water was dammed up. This is a clear case. A landslip may move a mass of earth and rock across a valley stream, and the water will be dammed up, and if the impediment is lasting, there will be a lake. Or a glacier may descend across the path of another, and the stream underflowing the last will be dammed up, and a glacier lake produced. In examining the structure of the earth near large lakes, proofs are afforded of former changes in it, and these preceded the formation of the original hollow, or else occurred whilst it was going on. Sometimes, as in Lake Superior, one side of the lake is formed of rocks and hills which have been stationary during the repeated sinking and upheaval of the earth in their neighbourhood; and, as in some of the Swiss lakes, the strata or layers of the earth are bent down in a remarkable manner close to the lake, and they appear to plunge below its floor. So vast were the movements of old at the eastern end of the Lake of Geneva, that some strata of vast thickness have been capsized and turned over. The southern hills of this lake were stationary more or less whilst all this curving and displacement occurred to the north. Breaking up of the surface for hundreds of feet must accompany such movements, and the disintegration or crumbling of the earth would be assisted by the streams, so that deep valleys would be formed. The mountain called the Righi, on the top of which tourists assemble to see the sun rise in the Alps, is close to another Swiss lake, and this hill has been turned upside down; and stranger still, the mountains out of which its pebbles were formed—for it is made up of water worn stones—have disappeared by sinking down below the surface. Sinking down would assist lake hollowing, so it is necessary to believe that crust movements and crumbling produced these

Fig. 5.—Lake Ionanga, Gaboon, Africa.

lakes, for it is evident that their water could not have hollowed them out. A theory, taught with great ability by Sir Andrew Ramsay, states that in the Glacial Epoch, when cold reigned supreme in the northern parts of the earth, the glaciers of the hills came into the plains, and, meeting with impediments to their progress, ploughed up the earth and made the great lakes. There is no doubt that the Swiss lakes were filled with ice to a certain extent, for rocks were carried from one side to the other on ice; but there could be no movement in a mass of ice sufficient to gouge out earth, in a hollow, hundreds of feet deep; and if there were, the earth gouged out could not be removed. It does not appear that the Alpine glaciers originally made the valleys in which they are found, though doubtless they enlarged both them and the fjords or lochs found on the western shores of so many countries. Accordingly this theory, which may be true for small tarns and lochs, and for some shallow valley-like lakes in the course of mountain streams, will not hold for the great lakes. The presence of volcanic matter, or of proofs of volcanic action having taken place near some lakes, is important; for Darwin and others have shown that after a volcano has been built up, there is a tendency for its base and the neighbouring district to sink down. Volcanoes are situated on lines of unstable earth; and it is very remarkable that the greatest depths of the modern oceans should be close to land where the volcanic action is or has been great. The undermining and falling in of the ocean floor by volcanic matters being abstracted, to make volcanic hills close by, is a cause of lake-formation on the grandest scale. The formation of circular lakes in the craters of extinct volcanoes is a collecting of water in a basin-shaped hollow, the rim being made up of matters cast forth by the same volcano. Lake Balaton is, of course, a striking instance of a lake having a volcanic origin, and Professor Judd has shown that it could not have been excavated by ice. Some small lakes may have been made by water pouring down on the rock through passages in glaciers when they covered the country; but many little lakes are found to have a relation, so far as their position is concerned, to cracks in the earth, which are called "faults"—cracks and displacements by which the surface of the earth has been let down on one side of a line. Rocks of different hardness are here brought against each other, and the softer wears off the more readily, and a hollow is made.

Hence a peaceful lake, hidden amongst the hills, the very emblem of quietude and rest, has a great, complicated, and somewhat stern ancestry, and its history from its birth is connected with the grandest movements and energies of the earth's crust

## THE RULER OF THE SOLAR SYSTEM.

By Richard A. Proctor.

I HAVE considered the nature of the celestial mechanism, and its mainspring. Now I have to describe the orb in which nearly the whole of that gravitating energy resides which is the mainspring of the solar system—the sun.

This noble globe, the mightiest and most massive body which we can see as a globe (though not the mightiest in existence), lies at a mean distance from our earth of about $92\frac{1}{3}$ millions of miles. His greatest distance (about July 1st) is nearly 94 millions, his least (about January 1st), rather less than 91 millions of miles. It may serve to give some idea of the vastness of the sun's distance (though we cannot in reality conceive such a distance, no matter how it may be presented), to mention that a ball fired from an Armstrong gun at the sun would require 13 years to reach him, supposing its velocity to continue unchanged throughout the journey. The sound of the explosion, if that could reach the sun, travelling at the same rate as sound in air, would reach him half an hour later. Light, although it travels at the rate of about 186,000 miles per second, takes 8 min. 18 sec. in reaching us from the sun (p. 190).

It is very easy to find out what the diameter of the sun is when his distance is known. It will be found that any round ball must be set at a distance equal to about $107\frac{1}{2}$, or more exactly, $107\frac{5}{12}$ times its own diameter to hide the sun exactly when he is at his mean distance (about April 1st and October 1st). Hence we learn that the sun's distance exceeds his diameter $107\frac{5}{12}$ times. His diameter is therefore about 860,000 miles, or exceeds the earth's nearly 109 times. It follows that the surface of

the sun exceeds the earth's about 11,750 times, while in volume the sun exceeds the earth about 1,260,000 times. Of these three relations, diameter, surface, and volume, the second—surface—is altogether the most important, since it is from the surface of the sun that we receive the supplies of light and heat which make the sun the light, as he is the life, of the solar system. Fig. 1 shows the relative dimensions of the sun and of the earth.

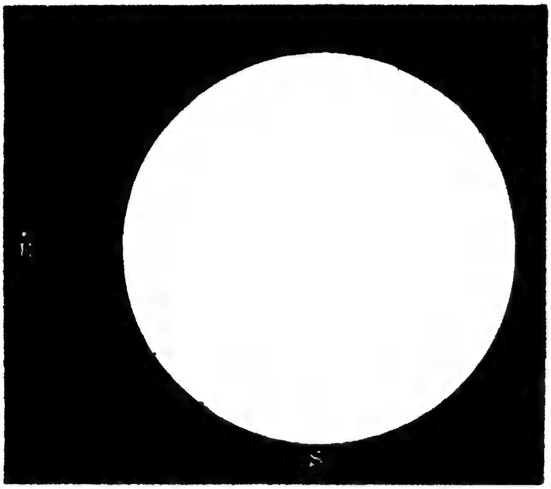


Fig. 1.—Showing the relative Dimensions of the Sun (S) and of the Earth (E).

But we have to consider next a relation far more important—that quality of the sun, namely, by virtue of which he is enabled to bear sway over the solar system—his mass.

I have not described how the sun's distance has been determined, because the various methods by which this has been done will require description in a separate chapter. But the determination of the sun's mass may properly be considered here.

We have seen that Newton proved the earth's gravity to be the force which controls the moon in her orbit, by showing that the force which draws bodies earthwards requires only to be reduced in a degree corresponding to the moon's distance, to become exactly equal to the deflective force earthwards which the moon constantly experiences as she circuits round our earth. Now, we know what is the deflective force sunwards which the earth experiences as she circuits round the sun. For we know her distance from the sun, and the length of the time (one year) in which her circuit is completed. When we calculate from these data* how great the force is which is constantly deflecting the earth sunwards, we find that the pull of the sun at the earth's distance is less than the pull of the earth on bodies at her surface (or 3,960 miles from her centre), in about the proportion of 1 to 1,675. But since the sun's distance exceeds 3,960 miles about 23,300 times, or is reduced (as compared with the earth's on bodies at her surface) 23,300 times 23,300 times, it follows that at equal distances the sun's pull exceeds the earth's as 23,300 × 23,300 exceeds 1,675, or roughly 325,000 times. When the calculation is made carefully, the exact distances being taken, we find that the sun's pull exceeds the earth's at equal distances 326,800 times. But we know that the force of gravity depends directly on the quantity of matter. Wherefore, we learn that the sun's mass exceeds the earth's 326,800 times. This proportion is not so great as that (1,260,000 to 1) in which his volume exceeds the earth's. It follows that his mean density is less than the earth's in the same degree that 326,800 is less than 1,260,000, or roughly his mean density is about a fourth of the earth's. More exactly, his density is to the earth's as 255 to 1,000. This is his mean density. The actual density of his internal regions may be far greater. Indeed, I see reason to believe, from certain circumstances recently recognised, that the central or nuclear parts of the sun possess enormous density. The mean density, however, of the sun, as we see his mighty orb, is only about one-fourth that of our earth. According to the best estimates yet obtained, our earth's mean density is about 5⅔ times that of water. It follows that the sun's mean density exceeds that of water about as 13 exceeds 9.

To afford an idea of the tremendous power residing in the sun's mass in virtue of its gravitating energy, let it be noticed that if our earth, without being larger than it now is, contained as much matter as the sun, every object on its surface would be drawn downwards with a force exceeding 326,800 times that with which it is actually drawn. Thus, a mass which now weighs one ounce would weigh 326,800 ounces, or about 9 tons. A man of average size would be crushed to the earth as under a weight of about 25,000 tons. A mass now weighing one

* I leave the calculation as an exercise for the student; but the following hints may help him:—Let him first find how far the earth travels in a second—he will find the distance to be about 18½ miles. Add the square of 18½ to the square of 92,300,000; the square root of the sum will be the earth's distance from the sun at the end of the second, if the sun's gravity had not acted; and taking 92,300,000 miles from this, we get the amount by which, under the action of gravity, the earth has been deflected towards the sun. It will be a very small decimal of a mile, and must be reduced to the decimal of a foot, for comparison with gravity at the earth's surface, which, as we know, causes a body to fall 32¼ feet in a second

ounce, if raised a single inch from the surface of the earth and let fall, would strike a blow as tremendous as if a mass now weighing 9 tons struck the earth with three times the velocity of an express train.

Such is the energy residing in the sun's mass. If we could imagine it all gathered into a point-like globe, this globe would exert the attraction just described on bodies at a distance of 3,960 miles. But as the sun's globe is very large, no mass is actually exposed to this tremendous attraction; for any mass outside of him lies more than 430,000 miles from his centre. But even at his own surface, or what seems to us his surface, his attraction is tremendous, exceeding terrestrial gravity $27\frac{3}{4}$ times. At the distances of even the nearest members of his family the sun's attraction is, of course, far less than terrestrial gravity. The motions of all the planets are such—the nearer travelling the more swiftly—that the sun's force suffices to keep most of those orbs travelling in paths of small eccentricity around him. Thus, their distances from him do not greatly change as they complete their circuits, and they receive from him a nearly uniform supply of light and heat. In the case of Mercury, however, and in less degree in that of Mars, the change of distance is large enough to make the supply of light and heat vary considerably in the course of the planet's circuit round the sun.

Now let us consider what the telescope tells us about this wonderful globe, the fire, light, and life of the solar system.

It was in the year 1611 that Fabricius, Galileo, and Scheiner first studied the sun with the telescope. They discovered that there are spots on the sun's surface. They saw the spots move across the sun's face from east to west, and at first they supposed these spots to be bodies travelling round the sun. But after a time they recognised the fact that the spots are, as it were, surface-markings, carried round with the sun's globe as it rotates on its axis. They also found that the spots are not permanent features, but last only for a few weeks or days, as the case may be. It would be interesting to follow the actual progress of their observations, and of subsequent telescopic study of the sun; but the requirements of space render it more convenient here to proceed at once to consider the results to which such researches have led.

Fig. 3 represents the general aspect of the sun as seen with a telescope of small power, when there are many spots. It was drawn by me on September 25, 1870, with a telescope only $2\frac{1}{8}$ inches in aperture and not much more powerful than the best of Galileo's telescopes. The figure of the sun is presented not as actually shown by the telescope, which inverted the image, but in its proper position—as also Galileo's telescope would have shown it, for the Galilean telescope does not invert objects seen through it.

It will be seen that the spots are not uniformly dark, but show certain dark, almost black portions, round which lies a region of dusky tint. The dark part is called the *umbra*, the border region is called the *penumbra*. When a telescope of considerable power is used, and the field of view is so reduced that only the umbra of a spot can be seen, it is found that the umbra is not black, and often there can be seen in the middle of the umbra a darker spot, which has been called the *nucleus*. Even this, however, is not black; for it has been found by Professor Langley, of Pittsburg, in America, that if a very small portion of the nucleus is examined (through a pin-hole opening) it shines with an intensely bright violet colour.*

The spots are often of immense size. One which was visible in August, 1859, had a diameter of 58,000 miles; another, seen in June, 1843, had a diameter of 74,000 miles, or more than nine times the diameter of the earth. The largest spot yet recorded was seen in the year 1858. It had a diameter of about 144,000 miles, and it has been computed that the cavity then existing in the sun's surface-matter would not have been more than filled by the substance of a hundred globes as large as our earth.

Fig. 3 shows that the spots on the sun are not only of different size, but of different appearance. Some, like the great central spot, show several umbræ, others show only one or two. These varieties belong in reality to different stages in the existence of a spot. When first fully formed, a sun-spot usually presents such an appearance as is shown in Fig. 2, a single umbra (in which, with higher power, there is a nuclear dark spot) surrounded by a penumbra, both umbra and penumbra having well-defined outlines. Later, the umbra becomes broken up by the apparent inrush of bright matter from outside the penumbra.

Fig 2—A Sun-Spot with a single Umbra.

The spots vary considerably in duration. Some

* During the transit of Mercury, on May 6, 1878, however, Professor Young, of Dartmouth College, Hanover, New Hampshire, found the same violet colour on the disc of Mercury. We must therefore suppose it to be the light of our own sky.

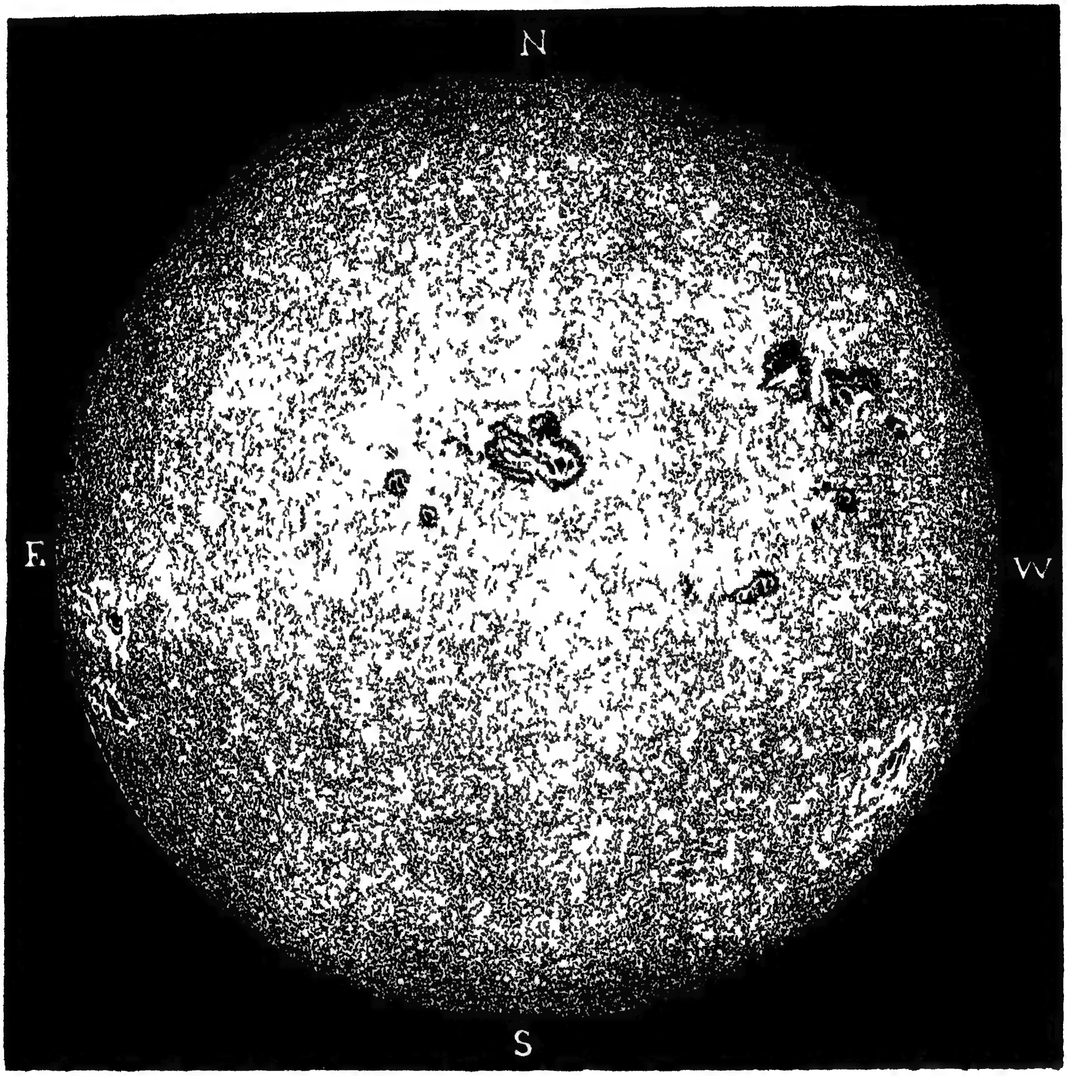
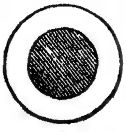



Fig 3.—The Sun, as seen by the Writer, September 25th, 1870

remain only for a few days, or even hours, others last for weeks, and a few have remained for several months.

While as yet a large spot shows only a single umbra, it usually changes little in shape, so that at this part of a spot's career it is possible, by studying its varying aspect as it passes across the visible hemisphere of the sun, to determine what its true shape may be—whether it is a mere surface-mark, or rises above the general level of the sun's surface, or lies below that level. Dr. Wilson, of Glasgow, observing in this way a very large roundish spot, which was visible on the sun in 1777, found that the dark part of that spot, at any rate (whatever might be the case with others), lay below the penumbra. I have said that the spots move across the sun's disc from east to west (Fig 3). Now it is obvious that such a spot as is shown in Fig. 2, if it were really a surface-marking, would be foreshortened in the same way whether on the eastern or on the western side of the sun. The spot would be narrowed, and the penumbra on either side of the umbra would be narrowed in the same degree. But if a spot is either an elevation or a depression, this will not happen. Suppose a spot is a saucer-shaped depression, for instance, the dark umbra corresponding to the bottom of the saucer. Let A (Fig. 4) represent the *interior* of a saucer, the shaded part being the bottom. Then such a saucer, placed in the position of a spot lying

on the hemisphere N E S W (Fig. 3), near E (Fig. 3), would appear as shown at C (Fig. 4); and if placed



A

**Fig. 4.—Showing how the Changes seen in Sun-Spots as they cross the Sun's Face are explained.**

in the position of a spot lying near W (Fig. 3), it would appear as shown at B (Fig. 4). Whereas, if A represents the *exterior* of a saucer, the aspect B would be presented by the saucer in the position of a spot near E, and the aspect C by the saucer placed like a spot near W. Now, Wilson noticed that the great spot of the year 1777 changed in aspect in the former way, not in the latter—that is, behaved in such a way as to show that the umbra lay below the general level of the sun's surface, the penumbra forming the slant sides of a saucer-shaped depression. He found that as the spot passed over from the middle of the sun towards the west, the penumbra, which had been equally wide all round, no longer remained so. On the eastern side the penumbra rapidly narrowed, while on the western side it remained unchanged in breadth, or nearly so. At length, when the spot had drawn very near the western edge of the sun, the eastern side of the penumbra disappeared altogether, while the western still retained considerable breadth. But when, after being out of view for half a rotation, the spot reappeared on the eastern side of the sun, its aspect was entirely changed. No penumbra was visible on the western side, while the eastern penumbra was broad and well defined. As the spot approached the middle of the sun's face the penumbra recovered its original equality of breadth. As the spot passed over to the western edge, the appearances before recognised in that neighbourhood were repeated.

It will be seen from Fig. 3 that the peculiarities of appearance recognised by Wilson are certainly not always displayed by sun-spots. But it so happens that nearly all the large spots which were visible on the sun when that picture was drawn were irregular in shape. They were in the later stages of a spot's career, when the umbra has broken up into several parts, and a general disturbance seems to pervade the entire region occupied by the spot.

Fig. 5 presents the appearance of a spot when the umbra has become broken up into several distinct portions. It also shows the different degrees of darkness of different parts of the umbra. Fig. 6 represents the aspect of a spot shortly before its disappearance.

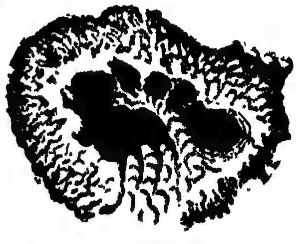


**Fig. 5.—Sun-Spot with several Umbræ.**

Under high telescopic power, the entire surface of the sun is found to be marked by minute irregularities. Nearly always there is a certain mottling of the solar disc, which can be recognised with telescopes of moderate power. But when the air is still and pure, and a high telescopic power is used, a much more delicate feature can be recognised. The whole surface is found to be covered with small intensely bright dots spread irregularly. These have been called the solar rice-grains. Under yet higher powers these bright dots become in turn divided into congeries of still more minute points of light. It is well to distinguish the three orders of irregularity as follows:—

**Fig. 6.—Last Stage of a Sun-Spot.**

First, the *mottling* which is visible with very moderate telescopic power.

Secondly, the *rice-grains,* to be seen only with a good telescope in favourable observing weather.

Thirdly, the *granules* which make up the rice-grains, and can only be seen with very powerful telescopes, and when the air is very still and clear.

We owe to Professor Langley, of Pittsburg, the recognition of the actual structure of the rice-grains.

In the neighbourhood of spots, and occasionally also where there is no spot, the irregular bright streaks can be seen, as though the rice-grains, which are usually spread with tolerable uniformity over the surface of the sun, had been crowded together in certain places, so as to form irregular ridges of brightness. These streaks were recognised by the first observers of the sun's spots, and received from Hevelius the name of *faculæ,* from the Latin word *facula,* a torch. They can be better seen near the edge of the sun than in the middle of his disc, where, indeed, it requires a good telescope to see them well, even round a spot. But they can often be seen encroaching on a spot, even near the middle of the sun's disc. Especially can these bright patches be thus seen in the last stages of a spot's career,

at which time they not only encroach on the penumbra, but often extend across the entire spot, forming bridges of intensely bright light. It is, in fact, usually by the invasion of these bright masses that the single umbra of a spot becomes broken up into two or more separate umbræ.

Near a spot the rice-grains are not irregularly rounded masses as they are elsewhere, but often appear elongated, a peculiarity which becomes more clearly recognised in the penumbra itself, which usually consists of elongated streaks directed towards the umbra. The peculiarity is partially indicated in Fig. 5. Fig. 7 shows a sun-spot as drawn by Mr.

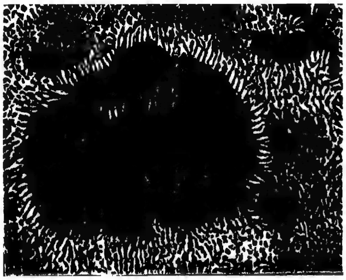


Fig 7.—View of a Sun-Spot, by Nasmyth.

Nasmyth, who gave to the elongated rice-grains the name of *willow-leaves*, by which they were long known. His opinion, however, that the whole surface of the sun is covered over with bright leaf-shaped masses interlacing, as shown in Fig. 7, has been shown to be incorrect. The best drawings of sun-spots yet made are those by Professor Langley, from one of which Fig. 8 is taken. It is intended specially to show the distinction between the bright rice-grains outside a spot, and the bright streaks in the penumbra. Professor Langley considers that the streaks and rice-grains are in reality the same objects, a rice-grain being a top view, while a streak is a side view, of a long bright filament.

It must be remembered always, however, that though the rice-grains and the streaks are spoken of as minute, they are in reality very large objects. The smallest granule probably has a diameter of more than a hundred miles, nor can the finest of the thread-like objects shown in Fig. 8 be much less than fifty miles in breadth.

The spots are not spread equally over the sun's globe at any time, nor are they equally frequent at all times.

Fig. 9 shows the two zones of the sun's surface on which alone spots are ever seen. E E′ is the equator, on or very near to which spots never appear. On either side are the two spot-zones, resembling somewhat in position the two temperate zones on the surface of our earth. In the sun's polar regions spots are never seen. *Faculæ* are not

Fig. 8.—View of a Sun-Spot, by Professor S. P. Langley.

limited to these two zones, though they are more frequently seen there than in either the polar regions or near the solar equator. The mottling can be recognised over the entire surface of the sun.

It has only been by the study of the solar spots that the position of the equator and poles of the sun, and the rate of the sun's rotation, have been recognised. The task has not been so easy as it would have been if the spots were marks on the surface of a distant rotating solid globe. It has been found that they not only move from or towards the equator, and parallel to the equator, but that spots at different distances from the equator have different rates of rotational motion, *as though* the equatorial parts of the sun's surface were turning round more quickly than the parts nearer to the poles. The equator seems to be carried round once in 24 days 2 hours; in solar latitude 15° N. and S., the rotation period is about 25½ days; in latitude 30°, it is about 26½ days. These are the real, not the apparent rotation periods; as the earth is advancing the same way round the sun as the spots are carried, and in the course of 24 days completes a considerable arc—nearly 15°—of her orbit, it follows that after a spot near the sun's equator has made a complete rotation, it has still to be carried round more than 15° before it *seems* to have made a complete rotation as viewed from the moving earth. Thus the apparent

rotation period of the sun is increased by rather more than a day.

The axis on which the sun rotates is inclined only about 7° from uprightness to the plane of the ecliptic in which the earth travels round the sun. Thus we never see the sun's equator much curved. It is shown in Fig. 9 about as much curved as it ever is, and as it appears about September 5, the northern pole being in view. About March 6 it is equally curved the other way, or with the convexity upwards, the southern pole being in view. On or about December 6 and June 5, the solar equator forms a diameter of the solar disc, the poles of the sun lying at the edge of the disc.

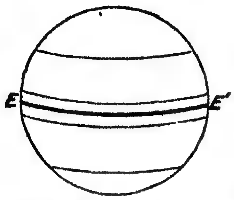



Fig. 9.—Showing the Zones of the Sun's Surface on which Spots appear.

The variation of the spots in number at different times is one of the most remarkable of all the facts known respecting them. The discovery was made by the late Herr Schwabe, of Dessau. From a series of observations commenced in the year 1826, and carried on for nearly half a century, he found that the spots increase and diminish in number in an almost regular manner. From the time when they are most numerous they gradually diminish in number, until at length none are seen; then after a year or two, during which scarcely any spots are seen, they increase in number until they again attain their maximum frequency. The entire interval between two successive epochs of greatest frequency is about 11 years 1 month. But although in any very long period this interval is recognised as the average, the actual interval between two successive epochs of greatest spot-frequency often exceeds or falls short of 11 years 1 month by two or three years.

Some peculiarities of this singular law of periodicity must be noticed.

The increase in the number of spots occurs somewhat more rapidly than the decrease, about 4½ years being the usual interval between the time of fewest and the time of most spots, and about 6½ years being occupied in the gradual diminution of the spots in number until none are seen.

As the sun is without spots for several successive months, it might seem as though the epoch of absolutely least disturbance could not be determined. But in point of fact the condition of the sun's surface changes notably even during the time when no spots are seen. The mottling becomes less and less recognisable, and finally disappears altogether for a few weeks. Again, the sun's disc, which at all other times is darker near the edge than in the middle, assumes for a few days a nearly uniform brightness. It is when this is observed that the epoch of least disturbance may be considered to have been reached.

As yet little is known respecting either the causes or the effects of these changes in the sun's condition. Mr. De la Rue and others, who have continued the work of systematically recording spots, believe that minor periods can be recognised, which they associate with the movements of certain among the planets competent (as they believe) to produce a sort of tidal action on the sun. But the evidence is very unsatisfactory. The opinion that the planets may thus affect the sun was based on the idea that the great eleven-year period of disturbance was due to the action of Jupiter, and synchronised with his motion around the sun. But it has been proved that the average of the spot-period cannot exceed 11 years 2 months, and Jupiter's period of revolution is about 11 years 10 months. The discrepancy is far too great to be overlooked. As the late distinguished solar observer, Carrington, remarked, the greatest number of spots may for a long time be seen when Jupiter is nearest to the sun, as though his greater disturbing action on the sun produced them in some way; but afterwards, for an equally long time, the greatest number of spots will be seen when Jupiter is farthest from the sun. As for the minor periods of solar disturbance, they have not yet been satisfactorily established; it will be time enough, when they have been, to inquire whether they agree with particular planetary periods. There are, however, so many such periods—the circuits of the planets round the sun, their conjunctions with each other, their passages to the north and south of the sun's equator, and of other planets—that we may be certain beforehand of finding a period of some kind which will correspond with every period of solar disturbance. This being the case, the significance of such agreement is very doubtful.

So, also, great doubt still exists with regard to the influence of sun-spots on terrestrial relations. An agreement was supposed to have been established between the great sun-spot period and changes in the earth's magnetism. But it is doubtful whether there is any real correspondence. At any rate, if the students of terrestrial magnetism are right in asserting that the period of magnetic change (the waxing and waning of the needle's diurnal oscillations) is

about 10 years, and if astronomers are right in assigning $11\frac{1}{9}$ years as the sun-spot period, it is quite certain that at one time the greatest magnetic disturbance will agree with the time of most sun-spots, while almost half a century later it will agree with the time of least sun-spots. Variations in the amount of heat received from the sun during the progress of the sun-spot period seem to have been indicated by the researches of Professor Piazzi Smyth, Astronomer-Royal for Scotland; but the changes are very slight. Weather-changes in different countries have been also associated by some with the frequency or absence of sun-spots; but I must confess the evidence appears to me thus far exceedingly weak.

A singular circumstance has been recognised with regard to the latitude on the sun in which spots appear at different parts of the great spot-period. As the spots get less and less numerous, it is found that the new groups make their appearance nearer and nearer (on the average) to the equator. But after the spotless interval, new groups appear at a considerable distance from the solar equator. The meaning of this peculiarity, the discovery of which is due to Carrington, has not yet been recognised.

We have thus far considered the sun only as the ruler of the solar system, and as the telescope presents him to us. We have still to inquire into the sun's actual condition, to learn what he is made of, at what heat he subsists, how the supply of heat which he constantly emits is probably maintained, and to consider also the wonderful appendages which surround his globe, but are visible only when the glory of his face is concealed in total eclipse. These matters are far too interesting to be dealt with cursorily in the short remaining space here available. They will, therefore, be separately considered in an account of the sun—our fire, light, and life.

To sum up what we have learned respecting the sun as ruler of the solar system:—

The mighty orb of the sun lies at a mean distance of $92\frac{1}{3}$ millions of miles from the earth, his greatest, mean, and least distance being relatively as the numbers 61, 60, and 59. His diameter is 860,000 miles, exceeding the earth's about 109 times. He exceeds the earth in surface 11,750 times; in volume 1,260,000 times; in mass (and therefore in attractive energy at equal distances) 326,800 times. The telescope shows that the sun's surface is not ordinarily of uniform brightness, but is marked by spots, which vary in size, number, and duration. The largest have had a diameter of more than 100,000 miles. Some spots last only a few days; others for several months. The dark central region of a spot lies below the general surface of the sun; but the evidence on which this conclusion is based can be depended on only when a spot is rounded in shape, and undergoing slight changes. Examined with high telescopic power, the sun's surface is found to be covered with multitudes of small bright dots, called rice-grains, which are themselves divided by higher telescopic power into still smaller points of light, called granules. The arrangement of the rice-grains into regions of greater or less aggregation produces the appearance called mottling; while the crowding together of the grains into long streaks forms the faculæ. In the penumbra of a spot the grains are seen as streaks of light. Spots are only seen on two zones of the sun's surface, on either side of the equator. But faculæ are seen all over the sun, though most frequently in the spot-zones. The solar equator-plane is inclined about seven degrees to the plane of the ecliptic. The earth crosses the extension of the sun's equator-plane on December 6th and June 5th. Spots wax and wane in number in a period averaging about $11\frac{1}{9}$ years; less marked periods probably existing, though as yet not certainly established. There is some reason for believing that the earth's magnetic condition varies with the condition of the sun, the time of greatest magnetic disturbance agreeing with the time of most spots; but this relation has not been demonstrated satisfactorily. When the spots first begin to show after a spotless interval, they are seen in high solar latitudes; but they appear in lower and lower latitudes (on the average), the last spots of each spot-period appearing quite close to the equator. If future observations should show this to happen in all spot-periods, the peculiarity must be regarded as probably of extreme significance. As yet, however, its meaning has not been recognised.

# WHY THE WIND BLOWS.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., Etc.,

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It is a very intelligible fact, as well as an inexorable law of nature, that two distinct bodies cannot occupy the same space at the same time. When two different bodies are pressed against each other, each resists the other as soon as they come into contact; and if the two are pressed against each other with unequal force, then the one which is most strongly pressed drives the other out of its way, and takes its place. In such case the familiar adage is certainly true—"the weaker goes to the wall."

A notable instance of this natural operation is seen when a lump of lead is dropped into a pail half-full of water. The lump of lead falls to the bottom of the pail; but, in doing so, it has to drive a bulk of water as large as itself out of its way, or it would never be able to get there. In this instance, however, as the lead *goes down*, the water is *driven up*. It cannot get through the wooden sides or bottom of the pail; and it is therefore driven in the only direction in which it can go—that is, up towards the open mouth above. If in the accompanying sketch (Fig. 1) *a a* represent the height at which the water stood before the lump of lead (L) was dropped into the vessel, *b b* would represent the height at which the water would have to stand after the lead had been placed in the pail. To produce this change, portions of water which are in the first instance at *c*, are *lifted* in the pail as high as *d*.

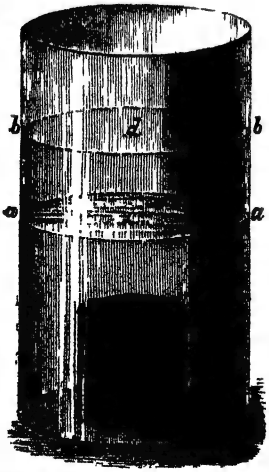


Fig. 1.—Showing Displacement of Water by Dropping a Piece of Lead into a Vessel.

There is, however, something else to be remarked concerning this enforced upward movement of the water, that is of still greater consequence on account of the bearing it has upon the subject of this paper. It is really caused by the downward pull of the earth, although the movement of the particles is the opposite way, or up from the earth. It could not with any propriety be said, in the circumstance which has been described, that the water moves up from the bottom of the pail to make way for the lead. That would not be a true representation of what had occurred, as it has been already shown that the water has moved up because it was pushed out of the way by the descending lead. The real and full statement of the case is that both the water and the lead are drawn to the earth in virtue of their weight. But the lead is eleven times heavier than the same bulk of water. It consequently is drawn to the earth eleven times more forcibly than the water; and the water resists the downward pressure of the lead with a strength that is eleven times too small to enable it to do so with efficiency and retain its place. The water accordingly yields to the superior downward pressure of the lead, and goes up out of its way; and thus it is the strong downward pull of the earth upon the heavy lead which lifts the water up towards the top of the pail. It is of the utmost practical importance that this should be clearly understood, because it is a great all-embracing natural truth that objects never move upon the earth from one place to another, unless they are driven to do so by the exertion of some active force that impresses them with the movement. The question, therefore, arises, since the water does move from the lower to the higher position in the pail, what is the force which drives it to do so? The answer to that question plainly is, The downward attraction of the earth upon the heavier mass, which, by its downward movement, pushes the lighter mass of the water out of its way. If a block of wood, of exactly the same size as the lump of lead, were dropped into the pail, it would not sink to the bottom of the water, like the lead. It would float upon the surface of the water with its own mass only a little way plunged in; and the reason of that would be that, whilst both the wood and the water were drawn towards the earth, the wood was less forcibly drawn than a quantity of the water which had equal bulk with itself, and therefore could not push the water out of its way to get down to the bottom of the pail. All this happens because wood is lighter than water, bulk for bulk, instead of being heavier, as lead is.

The invisible air, which floats everywhere about the solid bodies standing upon the earth, and which rests upon the water and the ground, is made of substance that has weight, and that is therefore drawn by terrestrial attraction after the same manner as water or lead, although its substance cannot be seen. A pint bottle, which seems to be empty, in reality contains 11 grains of air. The same bottle would hold something more than 9,000 grains of water, if water were poured into it in the place of air. Air is therefore 840 times lighter than water. Water can be poured into a bottle that was previously filled with air, because the water is heavier than the air. The water goes down into the bottle in consequence of its greater weight, and drives the lighter air up out of its way, just as in the experiment recently described the heavy block of lead drives the lighter water up out of its way, when it sinks to the bottom in the pail.

The particles, of which the invisible air is made, like that air itself, are incapable of being seen. One notable reason for this is that they are individually of very minute size. Very small specks of material substance can in some circumstances be seen by the human eye. Little shining particles of gold can still be perceived when they are so small that something more than one million and a quarter of them could be placed side by side within a square inch. And when the exceedingly powerful microscopes, which are now at the command of science, are employed in looking at them, objects that are exceedingly much smaller than this can be discerned. Such microscopes are capable of magnifying objects five thousand times in diameter. The surface of the speck of gold already spoken of might therefore be sub-divided into twenty-five million parts, and each one of those parts would still be within reach of the powers of the microscope. One very small thing that has been seen by the human eye when aided by the microscope, is the fine lashing tail of a minute living organism, called the *Bacterium termo*, which after long watching has recently been discovered by a very skilful observer, the Rev. W. H. Dallinger. The form which this pigmy of living creatures assumes when it is contemplated in Mr. Dallinger's microscope, with a power that magnifies its diameter 5,000 times, is something like that which is sketched in the accompanying figure (Fig. 2). From the mean of 200 observations Mr. Dallinger estimated the breadth of that fine moving streak as being certainly less than the twenty-thousandth part of an inch. But as the particles of the air cannot be seen by even this splendid instrument, they *must* at any rate be of smaller diameter than the twenty-thousandth of an inch, at which size four hundred millions of them could be packed in a square inch side by side, like the tiles of a mosaic pavement. How much smaller they may be it is not yet possible to say. But scientific men, such as Sir William Thomson, who concern themselves very much about the molecular composition of matter, and who therefore have the best right of all people to express an opinion upon the subject, conceive that a molecule which was not more than the twenty-thousandth part of an inch, would have to be again sub-divided, even into *many millions* of parts, before a size, like that of the ultimate atom which is concerned in fabricating such substance as the invisible air, is reached.

Fig. 2.—Form of Bacterium, as seen when magnified 5,000 Diameters.

Another familiar proof of the ponderous substantiality of this unseen and unseeable air is that which everybody experiences every day without taking any notice of it, until the attention is specially drawn to the matter. Like all other substances which possess weight, the invisible air *pushes* against bodies that stand in its way, when it is moving. It rushes against the face so that it can be felt. It turns the sloping mill-sails round when it drives against them, if travelling itself with sufficiently impetuous speed. It forces the ship, with its burthen of a thousand tons, to glide along over the sea when it strikes upon the broad canvas sails that are spread to catch the impulse.

But the minute particles of the invisible air, which are substantial enough to produce these very obvious mechanical effects, do not touch each other, as they exist in their natural condition in space. They float, in their inscrutable minuteness, certainly many times their own diameters apart. They may be driven to approach a little nearer together by the exertion of external compressing force, but they cannot be squeezed into contact by any power that man can bring into play for the purpose. They are not forced into contact by any of the incalculably greater powers that Nature herself deals with in her own majestic and mighty operations. They constantly stream and roll about amongst each other in all conceivable directions. Science, indeed, teaches that in all probability they are in perpetual unrest, and unceasingly

rushing about amongst themselves, and that when eleven grains of air-particles are corked up in a glass bottle, notwithstanding their apparent stillness, they occupy themselves with a never-ending dance during their forced imprisonment, each particle dashing from side to side, and to and fro, and never pausing an instant in its headlong and mad career, although it has all the time to wheel itself out and in and round its companion particles, to avoid coming into collision with them. Such is what science has, up to this time, been able to ascertain and to conceive in reference to the molecular constitution of air.

But, although air is so light that the quantity which fills a pint bottle, and which occupies 35 cubic inches of space, does not weigh more than a piece of card of the size of the figure which is here sketched (Fig. 3), its weight nevertheless

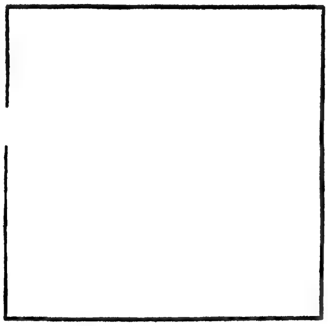

Fig. 3.—Piece of Card, to indicate Weight of Air occupying 35 Cubic Inches.

becomes a very important affair when large quantities have to be taken into account. The air stretches everywhere about the earth, and folds it all round, and extends out into space a very considerable distance away from the surface of the ground. No one yet knows exactly how far it reaches, because no one has yet been able to get far enough out to ascertain where it ends. But it certainly spreads more than fifty miles from the solid surface of the earth and from the liquid surface of the sea. The quantity, therefore, that rests upon an acre of ground, in consequence of this, presses down upon that space with a weight of no less than 22,000 tons! Fifteen pounds of it are sustained upon each square inch of the land that is near the level of the sea. This height of the invisible air was first ascertained at Florence, 235 years ago, by the Italian philosopher Evangelista Torricelli, in a very ingenious way, already partially sketched in another paper, but which, as to the illustration of our subject, we may here more fully describe. He took a glass tube, like the one sketched in this figure, which was a little more than 30 inches long (Fig. 4),

Fig. 4.—Illustrating Torricelli's Experiment for Pressure of the Atmosphere.

and which was open only at one end. Then, holding the tube perpendicularly, with the mouth upwards, he filled it with mercury, and placing his finger over the open end, turned it upside down, so that he could plunge the mouth into another quantity of mercury held in a broad basin or cistern (Fig. 5). He then found that the mercury contained in the tube fell a little way until it rested about 30 inches above the level of the cistern, and there stopped, leaving a small altogether empty space in the tube above its top. It was shortly afterwards shown, either by Torricelli or by Pascal, that the 30 inches of mercury were kept up in the tube by the weight of the air which pressed down upon the surface of the mercury in the cistern outside of the tube. The air was pressing down upon the mercury outside the tube at A, and the mercury, without any air, was pressing down upon the same liquid

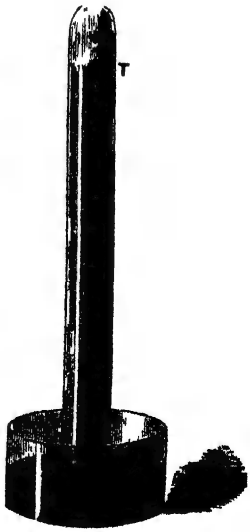


Fig. 5.—In Further Illustration of Torricelli's Experiment.

mass at the bottom of the tube at B, and the two exactly balanced each other by their opposing pressures, when the column of mercury in the tube came to rest at T, leaving the entirely empty space V above it. The column of air, which went up *more than 50 miles on the one side, was exactly of the same weight as the column of mercury which went up, on the other, 30 inches into the tube.* By *repeating the experiment with a tube that contained a cross area, or section, equal to a square inch, he afterwards found that it required just 15 lb* of mercury in the tube to resist or balance the antagonistic column of air, and he was thus able to show that a square column of air of the same size, or 1 inch across, and extending to the utmost limit of the atmosphere, weighed 15 lb. It was this experiment, first contrived by Torricelli, which led to the construction of the instrument called the "Barometer,"* or "measurer of weight"—that is, measurer of the weight of the atmosphere (pp. 71, 108).

But any given bulk of air is not always of the same weight. An inch-square column of the atmosphere sometimes weighs more than it does at others. This, therefore, is why the mercurial column of the barometer, which is the counterpoise of the equivalent column of the air, goes up and down from day to day within the glass tube of the instrument. The cause of this change of weight, however, is quite understood, and can be very easily explained. It is due to the fact that the little invisible particles of the air sometimes lie more closely together than they do at others—or, in other words, that any given bulk of air—such as a cubic foot—sometimes contains a greater number of air-particles in it than it does at others.

This effect can be produced by mechanical pressure. Air, under particular management, can be actually squeezed in, so as to be made to occupy less space. The operation would, of course, make the air specifically denser than it was before. That is to say, a cubic foot would weigh more after the compression than it did before. There are, however, other means by which the same result can be brought about. Cold, for instance, will do the same thing as compression. Imagine the case of 11 grains of air, possessing the ordinary summer temperature of 70°, being poured into a pint bottle, and the bottle being then surrounded outside by ice, while it is still left uncorked at the neck. This is what would then happen: The air inside the bottle would be made cold by the ice, and as it gradually became more and more cold, its little particles would be drawn more closely together, and so its entire mass or bulk would contract. But, as it did this, more air-particles would necessarily flow in through the open neck of the bottle, until at last it would be found that the bottle contained more than 11 grains of air, although its size had not been materially changed. In other words, the pint of air would have become heavier. If, then, the bottle were taken away from the ice, and placed over the flame of a spirit-lamp, as represented in the annexed sketch (Fig. 6), the air would become hotter and hotter minute by minute, and, as it did so, its little particles would be driven further and further asunder, so that many of them would be forced to rush away out of the neck of the bottle, until finally the bottle would have less, instead of more, than the original 11 grains of air in its inside—or, in other words, the pint of air would to that extent have become lighter.

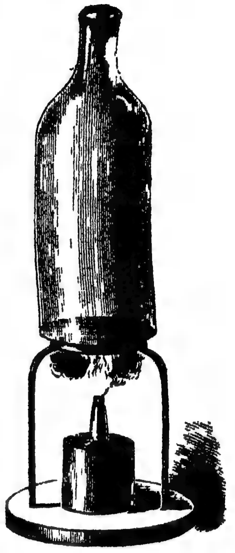

Fig. 6.—Illustrating Experiment of Air treated by Heat.

There is another very simple way in which the same effect may be, and is very commonly, shown.

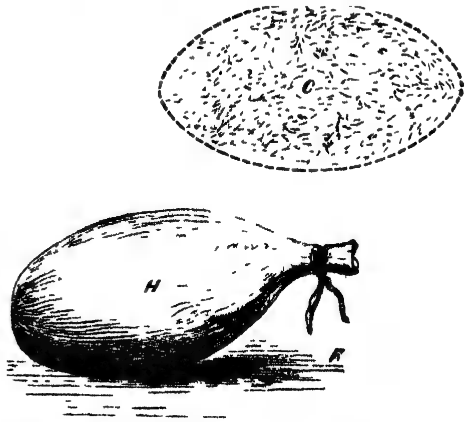


Fig. 7.—Illustrating Bladder Experiments with Hot and Cold Air

A bladder is tightly tied up at its neck, after it has been only half-expanded by blowing into it. Then, if it be held before a clear fire, it very soon swells up until it becomes smooth and tight. This

* From βάρος, burden or weight, and μέτρον, measure.

is caused by the expansion of the air in its inside, when the particles are driven more widely asunder by the heat. The bladder, if put into a pair of delicately-poised scales, would be found to weigh by air being rendered heavier by cold and lighter by heat.

A very remarkable consequence, however, follows from this change in the density of air from

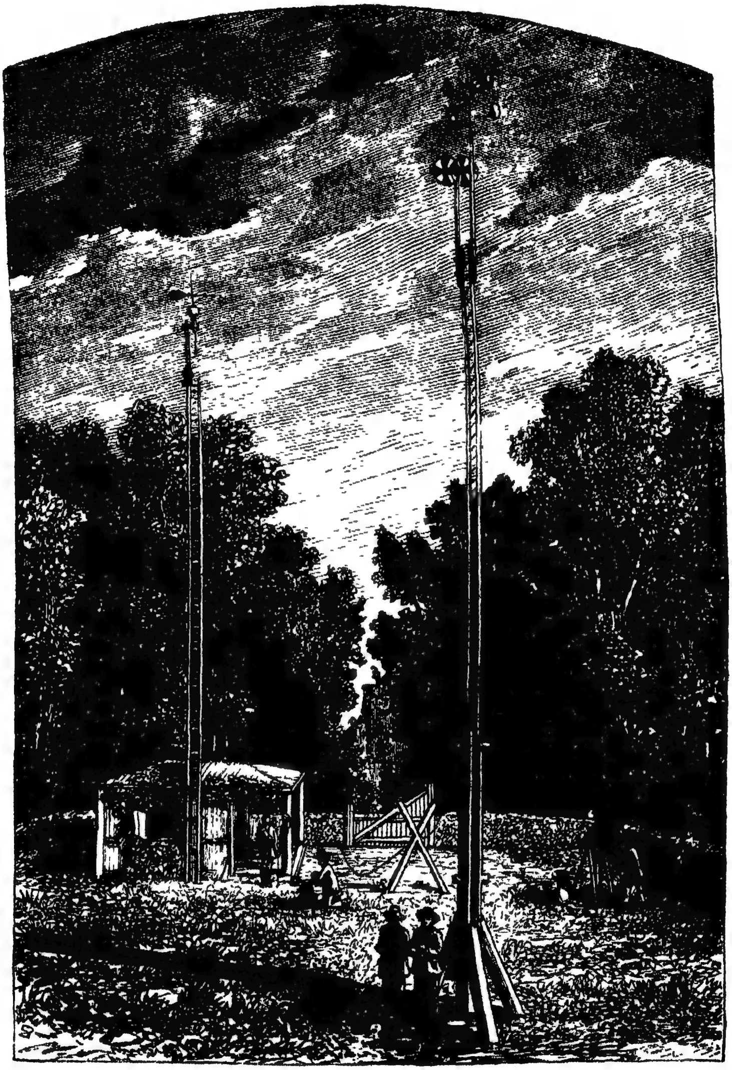

Fig. 8.—View of the Meteorological Observatory at Saint-Marie-du-Mont, Manche, France.

the same before and after its expansion. There would be the same *quantity* of air in it in each case. But if any given fixed *bulk*, such as a cubic inch, were taken out of it both before and after the expansion, it would be found that that cubic inch weighed more in the first case than in the last—just as the pint of cold air is heavier than the pint of warm. This it is which is meant differences of heat. Suppose that an exceedingly thin bladder of gold-beater's skin, so fine and thin that it is almost without weight in itself, be filled with very hot air, and be laid upon the floor in a moderately cold room, then all the equal bulks of cold air around and above will be drawn down towards the ground with greater energy or force than the bladder of hot air is. In the annexed

sketch (Fig. 7), let H be conceived to represent the bladder of hot, light air, and C an equal bulk of cold air just above; then the cold air C would be circumstanced just like the lump of lead, which was described a few pages back as being put into the pail of water. It would be drawn down towards the ground at F much more forcibly than H, the bladder of lighter air, and consequently it would fall to the ground under the stronger pull, just as the lump of lead fell to the bottom of the pail, and, in doing so, would drive the light bladder H up out of its way. The light bladder H would actually mount *up* towards the ceiling of the room, because the surrounding cold air was drawn more forcibly *down.* This, indeed, is exactly what the balloon is seen to do when it is filled with hydrogen gas, which is lighter, bulk for bulk, than even the hot air itself. The balloon mounts up into the open air for the same reason that some of the water in a pail ascends, when a lump of lead is thrown in to drive that portion of the liquid up out of its place. The balloon mounts in the air, in real truth, under the impulse of the same force that makes a stone fall through the air to the ground—that is, the attraction of the earth for ponderable matter. It merely goes up under the impulse, instead of going down, because, at the same time that it is drawn down, there is other ponderable matter by its side, which is more strong to descend than it is, in consequence of superior weight; and which, therefore, does descend, in spite of such inadequate resistance as is offered by the lighter mass, and in doing so drives the lighter mass up out of the place into which it forces itself.

It should now be a quite easy thing to understand why it is that the wind blows, and must blow, in the open spaces of the earth. In different parts of the world the sun shines with different degrees of heating power upon the ground and sea. Where it falls with most heating power, it warms, expands, and makes lighter the air. Where it falls with least heating power, the air remains unwarmed, unexpanded, and heavy, with its little particles squeezed more closely together. Both kinds of air, the heavy and the light, are drawn towards the earth, because both have weight. But the heavy air is more forcibly and energetically drawn down than the light, and on that account gets nearer to the ground. But in doing so, as two different bodies cannot occupy the same portion of space at the same time, it drives the light air, which is less forcibly drawn, out of its way. Suppose that, in the annexed sketch (Fig. 9), A and B are two places on the earth which are 50 miles apart, and that at B each cubic foot of air weighs 1,700 grains, whilst at A, on account of stronger sunshine and greater warmth, each cubic foot weighs only 1,675 grains; then, as the air at B presses down with more strength than the air at A, and as both, with all the intermediate

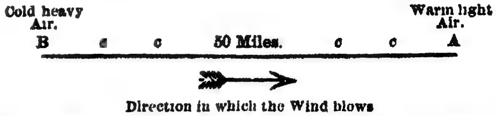


Fig. 9.—Illustrating Pressure of Hot and Cold Air on the Earth.

air along *c*, and *c* and *c* are, in consequence of the disconnected state of their particles, free to stream and flow in whatever direction they are impelled, the light air at A will certainly give way before the stronger pressure of the heavy air at B, and the air from B will rush along the ground towards A. But rushing or moving air is *wind.* There will consequently be a wind blowing from B to A. The air always thus moves from the place where its weight or pressure is most, towards the place where its weight or pressure is least. And in every case it moves with a velocity and strength which are greater in proportion as the difference of weight at the two places is greater, and which are less as that difference is less. Thus, if the wind were blowing from B to A, with a velocity of 30 miles an hour, when the air weighed 1,700 grains to the cubic foot at B, and 1,675 grains at A—if suddenly the weight of the air at A were changed to 1,650 grains per cubic foot, without any analogous change in the weight at B, the wind would then certainly blow from B to A with a velocity of 60, instead of 30 miles per hour.

It is now well understood that the wind is, in the main, at all times blowing from places where the air-pressure is great, towards places where the air-pressure is small; and the way in which it does this, under the circumstance of continually altering pressures, and of continually shifting situations of greatest and least pressure, has been reduced to a methodical explanation and expression, which is known as Buys Ballot's law, because a distinguished Dutch meteorologist of that name, has carefully and closely studied the subject. Buys Ballot's law, and also the kindred matter of the barometric gradient, which is connected with it, will, however, have to be more fully explained in another place.

The ventilating power of an open fire-place in dwelling-rooms depends upon precisely the same influence (p. 219). In establishing ventilation in the interior of a house, men simply create an artificial

wind to take the place of the natural wind which is shut out by walls and doors. When there is an open grate and chimney in a room, without a fire, the air presses down through the chimney-shaft, and in through the crevices of the windows and doors, with equal force, and is supported, as it does so, in a sort of even balance, by the air which fills the room. If, in such circumstances, however, a fire is lit in the grate, the column of air in the chimney becomes very hot, and, as it becomes hot, expands and gets lighter. The even balance is then, in consequence, disturbed. Heavy air presses in through the chinks of the doors and windows, and light air presses down through the chimney; but the light air has not resistance enough to withstand the strong pressure of the heavy air, and gives way before it, escaping in a continuous stream up the chimney, as the heavy air squeezes in upon it through the room below. The artificial ventilation of a room by a fire is thus again simply the movement of a wind from the place where the air-pressure is greatest, towards or to the place where it is least. As in the case of the external wind, the velocity of the air-current is in proportion to the difference of the air-pressure in the two places. With a very large fire, and with very hot air over it, the draught up the chimney becomes proportionally rapid and strong.

The air is kept in its place all round the denser substances of the earth by its weight. It is driven out of the way when bodies, which are heavier than itself, come into competition with it; but, when there are no more such heavier bodies to be brought into play, it is held fast by the earth, and piled up on itself further and further, and higher and higher, until there is no more to be so piled. It, however, gets thinner and thinner as it is further and further away from the solid ground, because in those outer regions it has less air-particles above it, and consequently less weight pressing it down, and squeezing its little particles into closer companionship. Every cubic foot of air, which is in contact with the ground, sustains upon itself an air-load of more than 2,000 lb., and is therefore squeezed in and compressed by that weight. But at the top of Mont Blanc, which is a trifle more than 3 miles high, each cubic foot of air would only have to bear a load of 1,000 lb. of the higher part of the atmosphere, and, in consequence, would expand into two cubic feet, of which each one would then contain 850 grains of air-particles, instead of the original 1,700. If a pint bottle with an open mouth, containing 11 grains of air, were carried up to the top of Mont Blanc, it would be found there to contain only 5½ grains of air-particles. The other 5½ grains would have been forced out through the neck as the air within expanded with the removal of the superincumbent weight. One-half of the actual substance of the atmosphere in reality lies within the limits of the height of this lofty mountain: the other half stretches out to a very much larger distance, because the thinning away of the air, under the removal of the superincumbent weight, goes on at a more rapid rate than the removal of the pressure. With increasing distance, the specific density is halved for each successive 3½ miles of ascent. If a cubic f ot of air weighed 850 grains at a height of 3½ miles, it would weigh 425 grains at 7 miles, and 106 grains at 14 miles, and it would still weigh 2 grains at a height of 35 miles. The highest point in the atmosphere, that has ever been reached by living men in a balloon, is 7 miles. It is almost certain that at a height of 8 miles no animal could continue to live. The atmosphere, in all probability, terminates externally where the natural expansion of its own thin and incoherent substance is balanced by the force with which the outermost range of particles is drawn in by the earth's attractive pull. As has been already stated, it is not yet ascertained at what distance that outer limit of the atmosphere is placed, but it is generally conceived by scientific men that the limit must lie somewhere between 50 and 200 miles above the level of the sea.

FIG. 11.—THE LEPIDOSIREN

# THE COUSINSHIP OF ANIMALS.

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A VERY considerable portion of the time of the naturalist is occupied in tracing resemblances and differences between different animals. Indeed, it may be maintained that the first beginnings of exact natural history study consist in the enumeration of these likenesses and distinctions, and in the endeavour to understand how they have been brought about and perpetuated. The chief difference between the commonplace observation of nature, and those exact methods and trained habits of investigating the world around us that we term, in one word, "science," will be found to lie not so much in the detection of likenesses, or in the discovery of points of distinction between objects, or between living beings, as in the appreciation and understanding of what the likenesses or unlikenesses are. The untrained observer may be quick and skilful to detect differences between two nearly-

related plants or animals, but he lacks the power to correctly express the results of his discovery. And as every fact in science bears a relationship to a greater or less number of other facts, the importance of being able to correctly express the results of research and to fit these results into their due place and order in the scientific edifice, may be readily appreciated. More especially is this the case, when the naturalist seeks to compare the parts or organs of one animal or plant with those of a different organism. On the estimate he may be led to form as the result of his comparison, depends the formation of opinions concerning the rank of an animal or plant in the scale of creation, or the determination of its place amongst its near relations. Whilst sometimes the very nature of an animal, or of some organ or part of a living being, is capable of being discovered only through the comparison of its structure with that of other organisms. The task of tracing likenesses and differences between living beings, is one in the pursuit of which a vast amount of interesting and instructive information may be gained. In the present paper, we intend to take a brief survey of the methods employed by naturalists when they endeavour to relate living beings to each other by a comparison of their structure; whilst from the illustrations selected to render these methods plain, several interesting facts in natural history may be brought under the reader's notice.

The class of Insects includes not merely an immense number, but a very large variety of animal forms. Its study might be regarded as a very complicated task; and so, indeed, it would be, were it necessary to gain a general knowledge of them for each species of insect that was to be studied and examined independently of its neighbour species. The naturalist expedites and facilitates his labours very materially, however, when he is able to show, firstly, that a general type or common plan of structure is discernible throughout the class; and, secondly, that his understanding of the differences between different insects depends on his acquaintance with the various modifications of the common plan he is able to trace and describe. These thoughts in reality afford the clue to the successful investigation of the world of life. Beneath the differences exhibited by the animals or plants of any great group, we are able to trace a certain broad likeness; and when we can successfully fill in the details of this likeness, we may be regarded as having advanced a very considerable way on our scientific investigation. There is one great principle which may be said to guide the naturalist in his researches into the likenesses and differences between living beings. This principle is named *Homology*. It may be defined as that which expresses the relationship between living beings or parts of living beings, that are essentially similar in their nature and structure. "Homologous" organs are those which are fundamentally the same. Or, to put it another way, "homologues" are organs that exhibit an identity of *fundamental structure* under every variety of form and function. Let us suppose, for a moment, that a watchmaker is shown a number of watches, constructed, some on one principle, others in a different fashion. However unlike the watches may be externally, their general structure is fundamentally the same. There is a mainspring, a balance-wheel, a winding-apparatus, face and hands, in each. Between the "lever" watches in his stock, the watchmaker would tell us there is naturally the closest of resemblances. The differences between watches with a movement different from that of the levers and the levers themselves would, of course, be readily perceptible; still the internal arrangements would partake of a strong likeness. Certain wheels in the one description of watch, would correspond exactly with wheels in the other set of timekeepers; and the mechanism connected with the hands would be of essentially similar character in all. A naturalist would therefore pronounce the watches generally to be *homologous* pieces of mechanism; and he might go further still, and say that they were specially homologous, when the arrangement and correspondence of their internal mechanism is understood. This would be his method of expressing the fact that the resemblances between the watches were of close and fundamental kind. The naturalist, moreover, might also say that the watches were *analogous* pieces of machinery. And why analogous? Because they perform the same function—that of timekeeping. But a carriage-clock, a chronometer, a lady's tiny watch, an eight-day clock, and Big Ben of Westminster, all possess the function of keeping time. Are these varied timekeepers analogous? Certainly. So that leaving out of sight any further comparison between clocks and watches, we have learned that when two things are fundamentally the same in structure, they are *homologous;* and that when two things perform the same function or work, they are *analogous*. The two conditions are essentially distinct the one from the other; although two things may be homologous and analogous as well. And as a last remark, we may call

attention to the term "fundamentally" used in these definitions. When we say that two things are "fundamentally" the same, we are making a tacit allowance for differences which may be perceptible between their structures or functions.

Applying these principles to the investigation of certain features of insect-structure, we may speedily discern their application to the studies of the biologist. No part of the insect economy presents greater variations in form or function than the organs which form the mouth. In the beetles we see the mouth organs adapted for biting and chewing. The butterfly, by their aid, sucks up the delicate juices of flowers. The land and water bugs pierce the skin of other animals by aid of their modified mouth-parts The bees and wasps may best be given through the means of an examination and comparison of the objects concerned.

Let us begin our examination of the insect mouth by looking at the parts seen in the mouth of a beetle or locust (Figs. 1, 2, 3). There are four distinct organs to be seen here. First comes an *upper lip* or *labrum* as it is called, which forms the upper boundary of the mouth. Next in order appear two large jaws,

Fig. 2 —Mouth of a Masticating Insect.

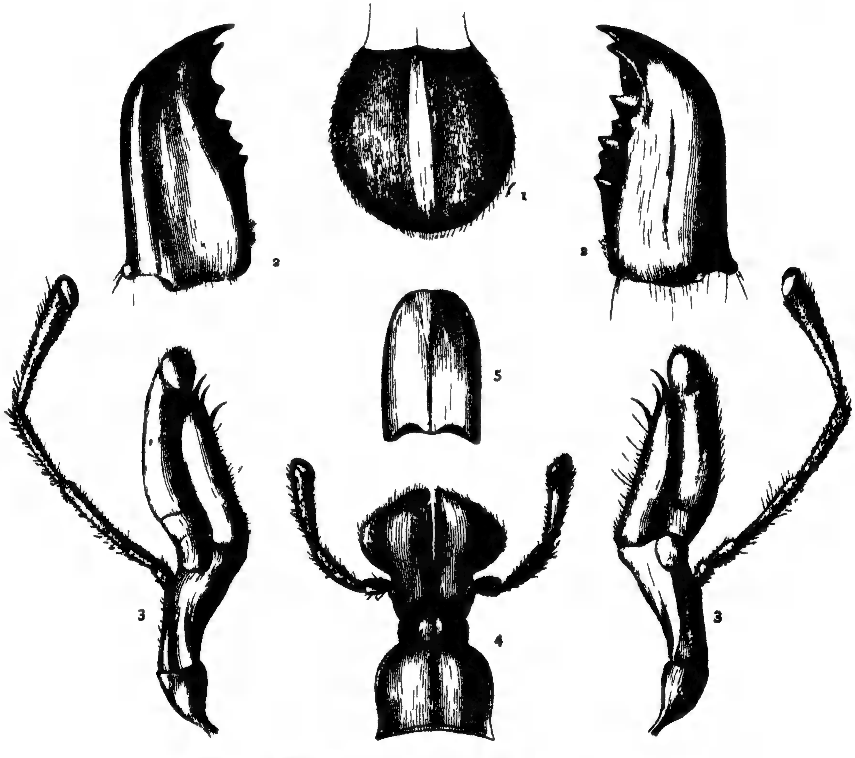



Fig 1 —Mouth-Parts of a Locust (*Locusta viridissima*).
(1) Labium or Upper Lip, (2) Mandibles; (3) Jaws, (4) Labium or Lower Lip; (5) Tongue

not merely obtain flower-juices by aid of their curious mouths, but also possess in these organs a multiplicity of tools, wherewith they construct those curious habitations for their large family-circles. Is it possible to trace any common type or plan underlying the very varied forms which the mouth of insects presents to our view? The only reply that can be afforded to the question, named *mandibles,* often having their edges cut into "teeth" well adapted for triturating the food. The third organs in the mouth are a pair of lesser jaws, known as *maxillæ*. These bear the *maxillary palpi*, or organs of touch, and, as some naturalists maintain, of taste as well. The use of the maxillæ appears to be that of aiding the mandibles in dividing the food and of retaining

the food in position whilst it is being masticated. The fourth and last mouth-part in the beetle consists of the *labium* or lower lip, which is formed in reality of a second pair of maxillæ joined together, and, like the maxillæ, bearing organs of touch, named *labial palpi.* The mouth-parts in the beetle and the locust are thus readily enough described. An insect of widely different habits is found in a butterfly; and at first sight the mouth organs of the butterfly (Fig. 4) appear to be essentially distinct from and utterly unlike those of the beetle. But a closer examination shows, nevertheless, that there are plain evidences of relationship between

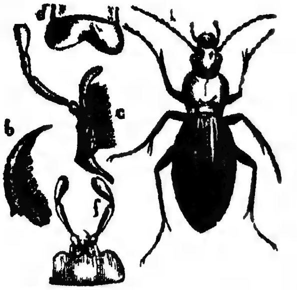



Fig. 3.—Parts of Insect's Mouth and Head.

Lip; (*b*) Man- or Jaws; (*f*)

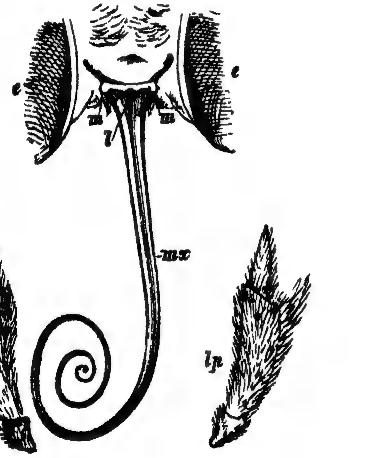



Fig. 4.—Mouth-Parts of a Butterfly.
(*e*) Eye; (*m*) Mandibles; (*mx*) Maxillary Palpi; (*l*) Labrum; (*lb*) Labium; (*lp*) Labial Palpi.

the two insects in respect of the mouth organs. The butterfly possesses a *labrum* or upper lip; this first organ of the mouth clearly corresponding with the similar part in the beetle. Where, however, are the butterfly's mandibles? Having no use for "jaws," we might naturally expect to find the insect lacking these organs. But Nature has a wonderful knack of preserving the symmetry of organs which are nearly related, and we are able to note that the butterfly does possess a pair of mandibles, though these organs are very small and rudimentary, and are of little or no use to the insect. Thus, the mandibles of the beetle are clearly represented in the butterfly. The *maxillæ*, or lesser jaws, are also to be seen in the latter insect, but we must be prepared to find that they have undergone considerable modification. Each maxilla of the butterfly is long drawn out to form a tube, named the *antlia*, or "proboscis," adapted for drawing up flower-juices, which the insect sucks in by means of its "sucking-stomach." This tube is often as long as the body of the insect itself, and can be folded or rolled up when not in use. The proboscis on transverse section is seen to consist of three tubes; the formation of these tubes being explained by the fact that, whilst the two long maxillæ form a tube by their union, each maxilla contains a little tube within itself. The *maxillary palpi*, or organs of touch, of the butterfly's maxillæ are present, but are of small size; and of the *labium* or under lip the same remarks hold good. The *palpi* or feelers of the labium, however, undergo quite a transformation in the butterfly. They were seen to be jointed filaments (Figs. 1, 3, *f*) in the beetle; but in most butterflies and moths they become developed to form two cushion-like organs, between which the proboscis is coiled when the insect is at rest. We have thus noted that the butterfly possesses all the parts found in the mouth of the beetle; and we have found that these parts, although presenting different appearances in the two insects, are essentially moulded on one and the same type. There can be no doubt, therefore, that the beetle's mouth and that of the butterfly are "homologous"—in other words, they exhibit the same fundamental structure, although their functions are of widely different kind. A further search in the insect class would show us some still more curious modifications of the one type of mouth found in the group. The bee, or wasp, furnishes a good example of an insect possessing a mouth which in one sense may be said to combine the characters of that of the beetle with that of the butterfly. The *labrum* or upper lip in the bee is readily recognisable; and no less so are


Fig. 5.—Mouth of a Bee.

the *mandibles* (*c*, Fig. 5), which are large and powerful, and form the implements by means of which these insects fabricate their hives and nests. The *maxillæ* (*d d*) are elongated in the bees, but their *palpi* are small, and they are much less jaw-like than in beetles. The *labium* or under lip, however, undergoes the greatest amount of alteration in the bees and wasps. It appears as a long, tongue-like structure (*a*), constituting the organ by means of which the insect collects the nectar and pollen of flowers; and its *palpi* (*b b*) are also greatly developed, to form protective organs for the labial "tongue." Once again, therefore, we find that a mouth apparently different from that of the insects we have previously examined, is in reality a mere modification of the common type found in the insect class. The familiar house-fly offers an example of another modification of this plan. Here (Fig. 6) the labrum is present, and the mandibles and maxillæ are represented by bristle-like organs, the maxillæ especially being of small size, whilst the palpi are also rudimentary. The labium or lower lip, however, once more appears as the modified organ, and forms the proboscis of the fly. This organ is folded up beneath the head when the fly is at rest. When, however, the fly alights on a sugar-basin, we see the elongated labium (Fig. 6) to be protruded from beneath the head. Its tip (Figs. 7 and 8) is expanded to form two broad, flat leaves, by means of which the fly laps up the dainties of which it is enamoured. Newport, a famous authority on insects, long ago called attention to the structure of the fly's proboscis, and to its roughened tip, and remarked on the amount of injury to the polished and delicate surfaces of furniture, books, &c., the organ is capable of effecting. The "tongue" of the fly acts like a kind of rasp; and, after attaining a knowledge of its structure, we can well understand how the scratched surfaces of our furniture—over which housewives lament after the usual summer plague of flies—have been produced. Whilst, also, we are able to form some idea of the manner in which the flies are able so continually and effectually to annoy ourselves, our horses and other quadrupeds. Thus we have seen that the mouth-parts in insects, despite variations in form and structure, are thoroughly homologous; and it only requires a careful examination of the series of mouth-parts presented by these animals to determine the unity of plan which prevails throughout the group.

Fig. 6.—Fly's Proboscis.

Fig. 7.—Extremity of Fly's Proboscis.

Fig. 8.—Lips of Fly's Proboscis.

Sometimes it may happen that the nature of an organ, and its correspondence with parts in other forms, can be detected only after the examination of many different animals. In such a case, we must trace the organ through the successive stages of modification it may be seen to pass, as we observe it in a whole series of animal forms. The mouth-parts of insects present us in each case with modifications already produced, and apparently of well-defined character. But in other instances we may require in the first place to determine the exact nature of an organ or part; and it is only after we have regarded such an organ in all its phases and stages of development that we can pronounce as to its real character and relationship. Such a case is well illustrated by the *air-bladder*, *swimming-bladder*, or *sound* of fishes. This organ is well known, in the case of the sturgeons at least, as that from the outer coat or layer of which isinglass is obtained. The royal fish is found in Britain and America, but it is in the Russian Empire where the different species attain the greatest abundance. The most famous among epicures is the small one, or sterlet; while the scene depicted on the opposite page is the fishery in Siberia of a larger species, from which most of the isinglass of commerce is derived (Fig. 9). Whatever its form in fishes, the air-bladder has but one function—namely, that of enabling the fish to alter its position at will, and to rise or sink in the water. Its use is that of a hydrostatic apparatus. By compressing the gas it contains, the body of the fish is rendered specifically heavier as compared with the surrounding water, and it is thus enabled to sink therein. The release of the air-bladder from the muscular pressure admits of the expansion of its contained gas, and of the subsequent rise of the fish in the surrounding medium. Now, the swimming-bladder varies greatly in form and structure throughout the class of fishes. In some fishes, such as the soles, flounders, sharks, rays, &c., the swimming-bladder is entirely absent. In its

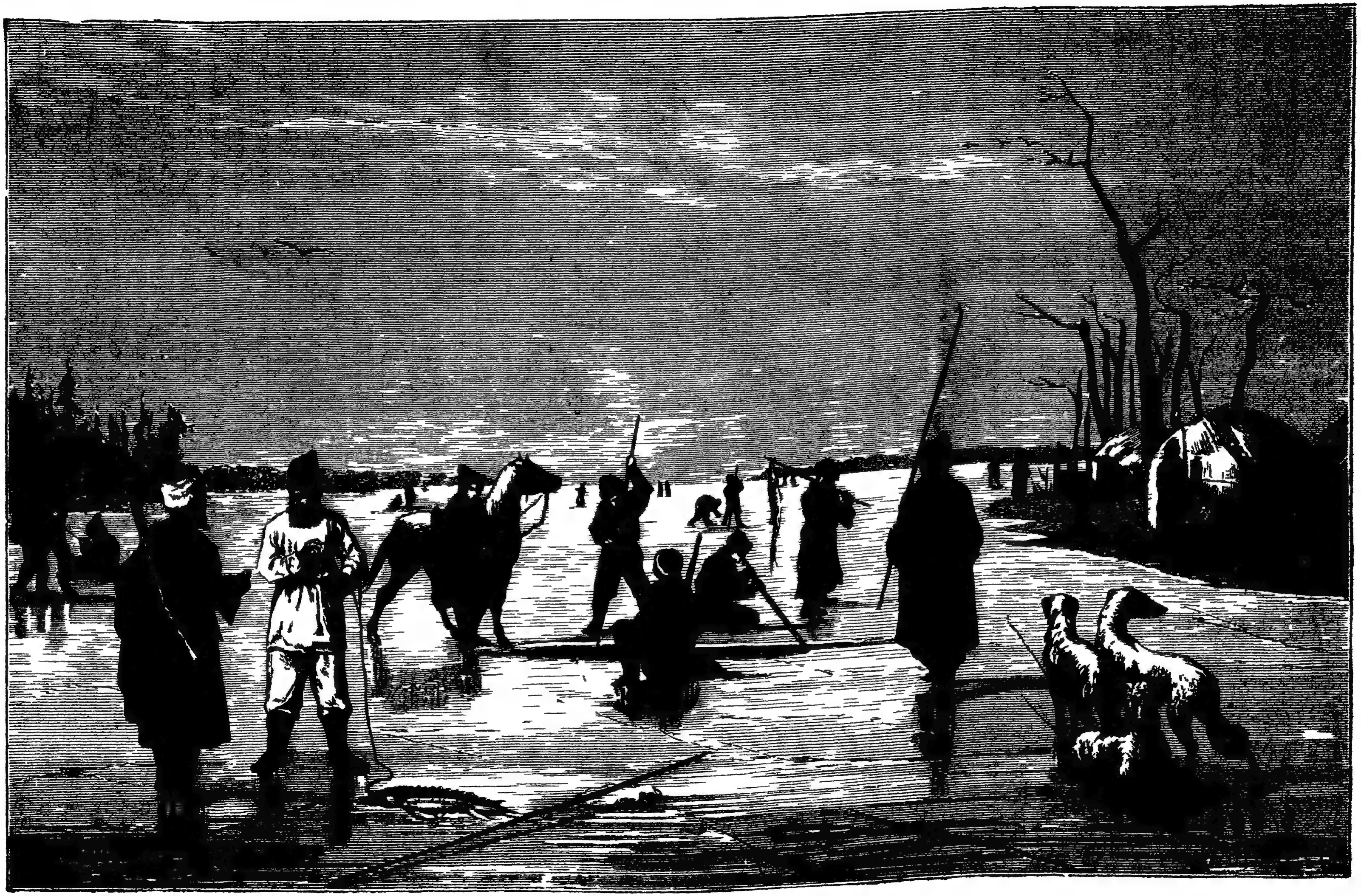


FIG. 9.—STURGEON-FISHING IN SIBERIA.

simplest form it appears as a shut or closed sac or bag, usually connected more or less intimately with the digestive system of the fish. This simple closed condition is well seen in the cod or perch; and in this state its relationship with any organ in higher animals is not traceable. When, however, we trace the nature of the air-bladder as developed in other fishes, we may find it to exhibit other details of structure. In the carp, for instance, the air-bladder (Fig. 10) is not closed, but communicates

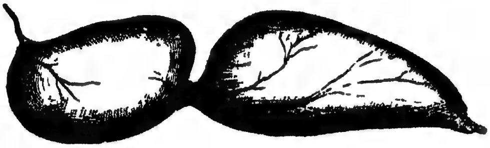


Fig. 10.—Swimming-Bladder of Carp.

with the gullet by means of a tube named the "pneumatic duct." In the herring, a tube connects the air-bladder with the front portion of the stomach; and in the carp and loach, in addition, it appears to be placed in close structural connection with the ear. In the presence of this tube we discover a step towards the solution of the nature of the air-bladder.

In the river Gambia of Africa and the Amazon of South America are found species of curious fishes to which the name of *Lepidosirens* (Fig. 11) or mud-fishes is given; and the Queensland rivers are tenanted by a curious fish named *Ceratodus*, and called the "Barramunda" by the natives. The mud-fishes swim about in their native pools and rivers in the wet season, and breathe by the gills with which they are provided. But on the advent of the dry season these fishes bury themselves in the mud, which dries around their bodies, and thus remain dormant until they are recalled to active existence by the return of the persistent rains. The problem how these fishes are enabled thus to live out of water is readily solved when the structure of their air-bladder is understood. This latter organ is double; it is divided internally into cells; and it opens into the throat by a tube or pneumatic duct which possesses all the characters of a windpipe. In the *Ceratodus* the air-bladder is almost similarly developed, the chief difference being that it is single or simple in its form, and not divided externally as in the mud-fishes. What, then, can be said of the nature of the swimming-bladder of fishes, in view of the information supplied by a review of its form in various members of the class? The answer is, that the swimming-bladder of the fish is truly *homologous* with the lungs of higher animals. We see in the pneumatic duct the first representative of a windpipe. But in the mud-fishes the development of the organ becomes more marked. Not merely is it divided or separated, as are lungs, into two halves, but its internal structure is cellular, and thus exactly mimics the conformation of a lung. Nor is this all. The physiological definition of a lung is that which regards it as an organ to which impure blood is sent from the heart, and from which purified blood is returned to the heart. The air-bladders of ordinary fishes are not lungs, since they do not purify blood. In the mud-fishes, however, the air-bladder is not merely lung-like in structure, but is also lung-like in function. It returns purified blood to the heart, and thus becomes not merely homologous with, but also analogous to, the lungs of higher animals. Thus we discover that the air-bladder of a fish in reality corresponds to the lungs of a reptile, bird, or mammal; and the true nature of the air-bladder is determined simply by the careful investigation of the organ throughout the class of fishes, and by the study of the variations it evinces in the course of its development in the direction of the lung.

Our search into homologies, and the manner in which their study leads towards the understanding of the true nature of organs or parts in animals and plants, may next lead us to consider briefly the interesting subject of the limbs of Vertebrate or back-boned animals, and their modifications. The limbs of vertebrates are well known to present some very singular modifications. Here we behold them in certain of the fins of fishes; there we see them in the fins of the whale, or the paddles of the seal and walrus. Now we see them carrying their possessor through the air, as in bat and bird; and next as the shapely extremities of the quadruped, or the facile arms and hands of man. Beneath this outward diversity of form and function, and different as these limbs are in their analogies, can we discover any indications of uniformity of plan or type? It is for the student of homology to reply; and his answer bears that the limbs of vertebrate or back-boned animals are constructed on one type. All the varied aspects of limbs are but modifications of a single plan, traceable, as a rule, without exceeding difficulty by the inquiring mind and "quiet eye."

The idea that a fish has limbs corresponding with the limbs of higher animals is one unfamiliar to the general reader. But if he will look at a herring, a salmon (Fig. 12), a cod, or a haddock, he will be able to see that whilst the back fins, tail fin, and anal fin

are situated in the middle line of the back, tail, and belly of the fish respectively, there also exist four fins disposed in pairs. The foremost of these paired

Fig 12.—Salmon.

fins, well seen in the herring and salmon, are named the *pectoral* or breast-fins, the hinder pair being termed the *ventral* or belly-fins; the ventral fin of the right side in the accompanying illustration of the salmon being the fin of the belly situated nearest the head. In the haddock, whilst the pectoral fins are placed on the breast of the fish, the ventrals are situated below them, and not, as in the herring and salmon, towards the rear of the body. The mere fact that these fins are paired at once suggests a resemblance to the limbs of other vertebrates, which are invariably paired organs. How is it possible to trace any further relationship between the breast-fins of the fish (which the zoologist asserts to be its fore-legs), the belly-fins (which he maintains are its hind-limbs), and the limbs of animals of higher rank in the back-boned type? Our reply is, through the deductions of homology; and by direct comparison of part with part, and of bone with bone.

Suppose, for the sake of simplicity, that we first examine the skeleton of a set of limbs with which we are familiar. No piece of anatomical study can be better adapted for our purpose than our own legs and arms. Look at the skeleton of the arm. There we find (1) an upper arm consisting of a single bone, the *humerus* (*a*, Fig. 13); (2) a fore-arm consisting of two bones, *radius* and *ulna* (*b c*); (3) a set of small bones—eight in number in man—forming the *carpus* or wrist (*d*); (4) five bones forming the palm or *metacarpus* (*e*); and (5) the fingers, each consisting in man of three small bones or *phalanges* (*f*), save the thumb, which has but two. Examine now the fore-leg of such an animal as the horse. Externally the arm of man and the fore-leg of the horse are not alike, but a mere glance at the skeleton of both serves to show a close identity of type. In the horse we find a well-developed upper arm or *humerus*. The fore-arm, with one of its bones (the *ulna*) much reduced in size, is also quite apparent. Seven wrist-bones (*d*, Fig. 14) are easily observed; but it is equally clear that the horse's hand is greatly modified. There is only one finger or toe—the


Fig 13.—Bones of the Human Arm.

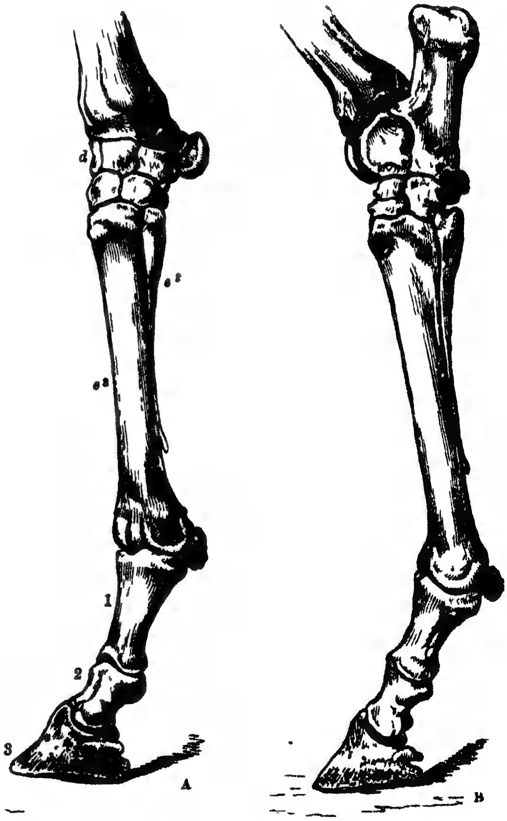



Fig 14.—Bones of the Fore (A) and Hind (B) Limb of Horse.

third or middle one—developed in the horse on each foot; and the bone ($e^3$) of the horse's palm corresponding to this finger represents in itself the greater part of the palm or *metacarpus* of man. But on each side of this single bone are to be seen two small pointed bones, named the *splint-bones*. (One of these is seen at $e^2$.) With what, in man, do the "splint-bones" of the horse correspond? There can be no doubt that they represent the rudimentary metacarpal or palm-bones of two fingers—the second and fourth—which have dwindled away until they have become mere shadows of their former selves. Despite its outward dissimilarity, the horse's fore-limb is thus seen to be homologous with the arm of man. The hind-limb of the horse (B, Fig. 14) exhibits an essentially similar arrangement of parts, as may be learned from a glance at the accompanying figure.

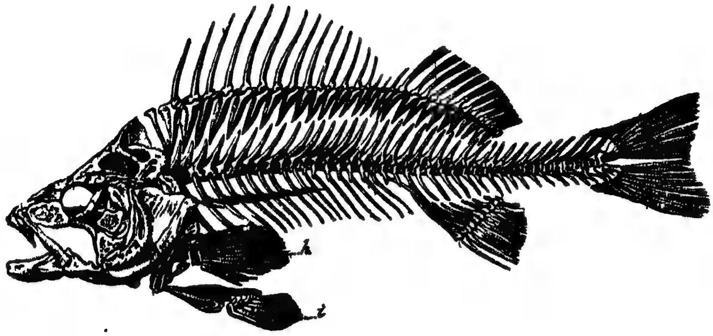


Fig 15.—Skeleton of Perch

In the "paddle" of the whale there is no difficulty in recognising a member related to both of the preceding examples. The fore-limb of the whale is shortened, it is true, and inclosed within the skin so as to adapt it for swimming; but its skeleton more closely resembles the arm of man than did the fore-leg of the horse. The wing of the bird should correspond to the fore-limbs of other vertebrates, and so in truth it does. The bird possesses a humerus, or upper-arm bone, and a radius and ulna in its fore-arm, but its ulna is larger and stronger than the companion bone; thus reversing the condition of matters seen in the horse. The wrist of the bird appears to consist of but two bones; but it is a wrist nevertheless; and there are three fingers—the thumb, second finger, and third finger—much modified, and concealed, as are the other bones of the wing, beneath the skin and muscles. Once again, we find fundamental likeness and a similar structure beneath outward dissimilarity of form. The case of the fish (Fig. 15), to which we may lastly turn, is perhaps the most instructive example of the correspondence between the limbs of vertebrates, even if the relationship of the paired fins to other limbs is also more difficult to trace. Zoologists are not quite agreed as to the exact parts in the skeleton of the pectoral fins ($h$) of the fish which represent the various parts of the limbs of other vertebrates, but there is no question of the homology and correspondence, nevertheless; and further research may hereafter render the comparison clear and evident. The ventral fins ($i$) clearly correspond to hind-limbs, as already remarked. Thus our ramble in search of correspondences has again resulted in our learning that, however different the limbs of vertebrates may appear, their structure and build is essentially the same wherever they are found. In other words, they are "homologous" organs in the truest sense of the term.

The labours of the zoologist are thus seen to be of a more than usually interesting character when he endeavours to relate the various organs and parts of one animal of a group to those of a different animal or division. It is right, however, that we should point out, by way of conclusion to our present study, that this work of tracing likenesses between different animals is fraught with a larger measure of importance than that derived from its purely zoological side. When we learn that organs used for widely different purposes are in reality founded or constructed on a common plan, the idea has been raised that such organs or parts may have had a common origin. There are one or two important features still to be noted in connection with the modifications of organs or parts in a series of animals. It may be asked if the inferences or conclusions of our studies are in any way susceptible of direct proof? Thus it has been inferred from the history of the air-bladder of the fish, that the lungs of higher animals represent a modified and highly-developed swimming-bladder, adapted through its high development for the function of breathing. Its first well-defined stage is seen in the mud-fishes; and in the animals (frogs, newts, &c.) which rank next in order to these fishes, the lungs have not increased very greatly in complexity over the altered air-bladder. In the class of fishes, we observe this organ presents a

gradual advance in complexity towards the form and structure of the lung. But in the case of the limbs of the horse, there is well exemplified the manner in which the study of homologies leads to the knowledge of how the horse is related to some of its humble relatives, which, having played their allotted parts in past periods of the world's history, are now known only by their bones, entombed in the soil over which they grazed. We have determined through our study of limbs that the horse possesses on each foot one fully-developed toe (Fig. 14, $e^3$, 1, 2, 3)—the middle one—on the greatly developed nail and hoof of which the animal walks. And we have also noted that there exists on each side of this well-developed toe a "splint-bone" ($e^2$); these splint-bones being merely the rudiments of the bones supporting the second and fourth toes. Such is the state of matters in the existing horse or *Equus* of the zoologist. If we turn to the horses of bygone ages, and read in the "records of the rocks" the past history of the horse-family, we shall find, firstly, that the bones of horses preserved as fossils in the Recent, or last-formed rocks, are essentially like the bones of the horse of to-day. In rocks a little older (Pliocene and Miocene), the bones of extinct horses also occur; but the study of these bones shows us that the two "splint-bones" are greatly developed—so much so, indeed, that had we seen these Miocene horses in existence, we may be certain we should have observed them to possess two rudimentary toes, or "dew-claws," in addition to the well-developed third toe. Such horses are named *Hipparion* and *Protohippus*, the former being the three-toed fossil horse of European rocks, and the latter of American deposits. For curiously enough, in America, where the modern horse was unknown until the Spaniards arrived, various kinds of horses seem, in former periods of its history, to have been abundant. Thus far, homology is being assisted and guided by the study of fossils, as in its turn it has assisted the geologist in comprehending what the "splint-bones" of living horses really represent. In European rocks, older than those in which Hipparion occurs, we find another fossil horse, named *Anchitherium*: this animal being represented in American rocks of like age by the extinct horse named *Miohippus*. In these latter horses, the two rudimentary toes are seen to be well developed, and apparently these toes may have rested on the ground, whilst, in addition, a rudimentary, or "splint-bone," representing the fifth or little finger, was developed. In formations older than those which contain the *Miohippus* remains, another extinct horse (*Mesohippus*) is found, in which the little finger attains still larger proportions. Last of all, in the Eocene rocks [*see* FRONTISPIECE], which are older still than the Mesohippus-formations, we find the oldest fossil horse yet known. This is the *Orohippus*, possessing four well-developed toes on its fore-feet, and three well-developed toes on its hind limbs. The bones of the leg, deficient in existing horses, are further well developed in this oldest form. When the history of the horse shall have been more completely investigated, we may safely expect to meet with forms in which all five toes were well developed on both fore and hind limbs; and even now there is evidence that in the *Eohippus* recently discovered in the formations of Western America, we are brought a step nearer to the typical five-toed animals, the oldest twig of the equine genealogical tree. There is thus bound up with the tracing of homologies a most interesting field of speculative philosophy; for though the old horses are fact, the deductions from them are purely speculative, but are at the same time of rational and likely kind.

The brief study detailed in the foregoing pages hardly requires any application or summary of its chief features. These latter, indeed, are plainly manifest in the study itself, and the story told us by the laws of homology carries its own moral. It is, however, not the least interesting feature of such a subject, that it demonstrates forcibly the bonds of relationship that link together beings often of widely diverse nature, and shows us the unity which prevails amidst an apparently diverse aspect of life. Into the deeper issues of the study—how and why homologous parts and organs are developed—we do not presume to enter. And, even if we do not advance beyond the mere recognition of the resemblances which the study of homology discovers, we may still congratulate ourselves on having been able to see no inconsiderable distance into the methods and ways of living Nature.

# A NETTLE-STING, AND OTHER PLANT HAIRS.

By Henry J. Slack, F.G.S.,

*Formerly President of the Royal Microscopical Society, etc.*

Most persons have made an unpleasant acquaintance with one form of plant hair through being stung by a nettle, but comparatively few have paid any attention to the exact nature of the offending organ, much less considered its relation to similar structures on other plants. The stinging hairs of the nettle belong to the class of "glandular hairs," and they consist of the glandular, or secreting part, at the base, and of the conical tube arising from it, and most often ending in a very sharp point. A simple plant hair is an out-growth from the epidermis, or plant skin; but those with glands at their base may, as Sachs explains, be partly formed by cells of this *epidermis*, and by a layer of the vegetable tissue below them. A gland may consist of one or more cells. In the nettle there are several. The function of a gland is to separate some peculiar substance, such as oil, resin, camphor, &c.; or a poison, as in the nettle and other stinging plants. Many plants that have scent glands (sweet herbs, scented geraniums, &c.) easily yield a portion of their contents to slight pressure; the nettle as readily parts with its poison, which the sharp hairs insert into the skin of the person inadvertently touching it. The annexed figures (Fig. 1, A, B) show the most common forms of nettle-stings, but some have little round knobs at their tips. If a vigorous leaf is examined under the microscope, or with a hand-lens of about an inch focus, each tubular hair will be seen wholly or partially filled with a colourless fluid. If while under examination one of these hairs is pressed with a needle, the fluid will be seen to move. If a glove is put on the left hand, a nettle-leaf twisted round the forefinger with its upper side outermost, and held up to the light, the stinging hairs may be readily examined with a small magnifying-glass in the right hand; and if any one of them is touched with the nail of the middle finger a movement of the fluid contents will be noticed. A few hairs may be picked out of the leaf with a needle, taking also a little of the leaf tissue, avoiding injury to any part of the structure. The hairs may then be placed on a glass slide, covered with thin glass, and put under a microscope with an inch power. If the covering glass is pressed with a needle while the objects are under view, the fluid will be seen to run out, often without visible injury to the hair.

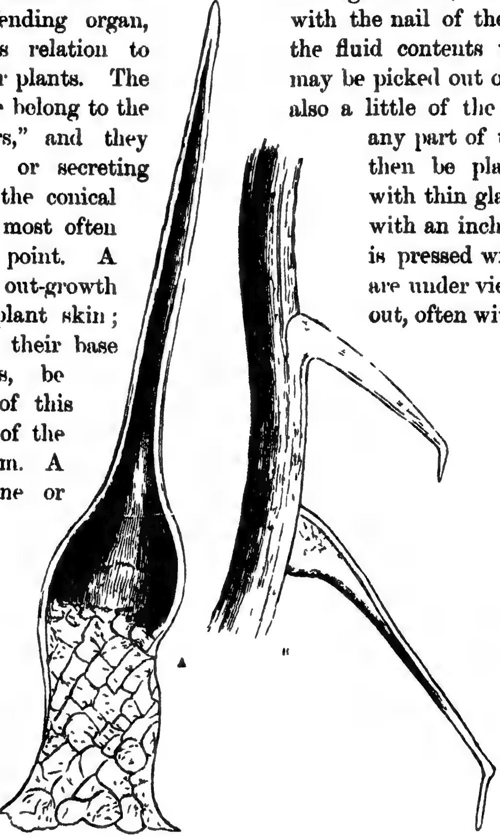



Fig 1.—Hairs of Stinging Nettle. (*Magnified 90 diameters.*)
(A) Large Hair, (B) Smaller, growing from vein, tips broken.

One writer says that the well-known plan of grasping the nettle to escape its sting succeeds because the hairs are broken off below their sharp points, and cannot pierce the skin; but a great many trials show that the hairs are very often by no means so brittle as this notion supposes. The English nettle is very innocent compared with some of its foreign relations. In the northern part of New South Wales, for example, the Giant Nettle (*Urtica gigas*) sometimes reaches the height of 120 to 140 feet, and its leaves, 12 to 15 inches broad, are armed with prickles that produce severe, and sometimes dangerous effects. In Timor and Java, also, is found the Daoun Setan, or "Devil's Leaf," reported to be able to cause death, or at least to produce such effects that the pain will last several years, and be acutely felt during moist weather. There is, also, in India, a nettle which stings so fiercely that it is to be avoided at all times, but especially in the autumn. The pain from its poison is intense, and has sometimes been known to produce symptoms very like lockjaw; while in New Zealand is found another which causes itself to be held in painful

remembrance for several days after the unwary bush-traveller has made its acquaintance.

A plant hair may, by thickening and filling up, be converted into another kind of defensive weapon, as in the thorns of the roses, and similar structures which spring from the epidermis, and are distinct from spines that are on growths of wood and have a deeper origin—in a word, stunted branches. The largest rose-thorns are easily broken off by lateral pressure, and are then seen to be of superficial origin. Various cactus plants also exhibit remarkable prickles, which are modified hairs, some of them growing in tufts, each one extremely sharp-pointed, and barbed like the fish-spears of South Sea Islanders. An incautious finger is speedily afflicted with a whole sheaf of them, and made acquainted with the merit of their barbing by the difficulty of their extraction. Some of the larger cactuses form excellent hedges, and are no insignificant means of fortifying villages in Africa and elsewhere. Various plants with thorns and prickles of an analogous description oppose almost invincible obstacles to travellers in the bush of many wild regions.

The barbs of certain thorns are lateral growths, and we find many hairs exhibiting this departure from linear development in a more striking way. One of the prettiest illustrations of this may be found in the leaves of the *Deutzia scabra* or *gracilis*, especially on the upper surface. The cuticle of these plants, with its star-like hairs, mounted in

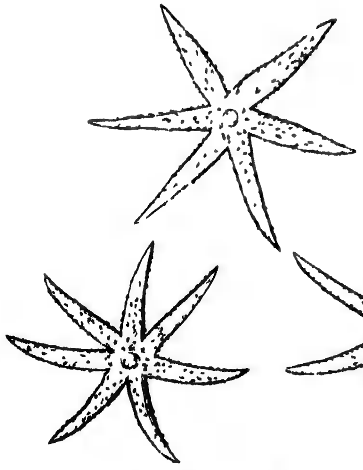


Fig. 2.—Star-shaped Hairs of *Deutzia scabra* (*Magnified 90 diameters.*)

Canada balsam, and viewed under the microscope with polarised light, forms a well-known and extremely beautiful object (Fig. 2). If a Deutzia leaf is heated over a spirit-lamp on a metal plate until it is charred and turned black, the hairs shine out distinctly, having preserved their form in consequence of their being strengthened with a deposit of silica, or flinty matter, which the temperature necessary to burn the

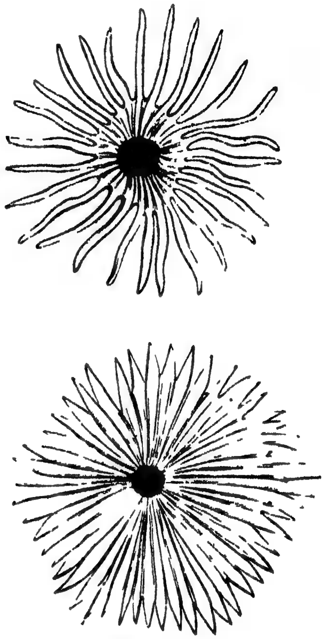


Fig. 3.—Star-shaped Hairs from Leaf of *Heritiera minor.* (*Magnified about 90 diameters.*)

vegetable matter does not affect. More complicated star-like hairs adorn the under-surface of the leaves of many plants, amongst which may be mentioned the oleaster (*Elæagnus*), and *Heritiera.* A species of *Elæagnus* is grown in English gardens, but the one before us is *E. argentea*, thickly set with minute many-rayed stars, that require a magnification of fifty or sixty times linear and a strong light to reveal their beauty. The *Heritiera* is cultivated in the West Indies, and called the "Looking-glass Tree," from the brilliant silvery aspect given to the under side of its leaves by hairs of similar structure. These leaves vary in the arrangement of the rays, some having a sort of rosette in the middle. Fig. 3 gives one of each sort. Coarser stellate hairs of similar character are found on the leaves of the tree that produces the remarkable Durian fruit of the Indian Archipelago, and which is said to reward the bold experimenter who ventures to eat it—in spite of its diffusing a powerful odour of bad meat—with a combination of the most exquisite flavours. The sepals of Gum Cistus are also decorated with stellate tufts of white hairs.

In many well-known plants the general aspect of

the leaves is hairy; but this decoration or clothing does not amount to a disguise. Not so, however, with a New Zealand plant, that is sometimes taken at a little distance for a sheep in repose. This curious member of the vegetable kingdom grows in tufts or hummocks of considerable dimensions. Its stems are very short, closely compacted, and very hairy, so that it only exhibits a dense woolly surface. When pulled to pieces it is found that each tuft is composed of thousands of a composite flower, closely packed together, and each one contributing its quota of woolly-looking hairs. Its name is *Raoulia eximia*, or Vegetable Sheep.

Among the common English plants, London Pride is remarkable for the beauty of the ruby-tipped hairs about its stem; and, though almost too short to be called hairs, but belonging to the same class of structure, are the little red spherules with short stalks all round the edge of sweet-briar leaves. Similar glandular hairs are thickly set on the under-surface of these leaves, some with red, others with white little balls at their tips. The anthers of many plants are supported by hairy filaments. Sometimes their hairs are straight and simple, at others branched, or bulbous. The Bog Pimpernel (*Anagallis tenella*) exhibits them with elegant lateral expansions. In *Tradescantia Virginica*, or Spiderwort, that puts forth its rich purple three-petaled flowers in June, the filaments are adorned with a multitude of exquisitely beaded hairs of the same tint as the flowers. A portion of a filament with some of the hairs (chiefly those on one side) is shown in Fig. 4.

In Virgin's Bower or Traveller's Joy (*Clematis vitalba*), the seed-vessels put forth a remarkable quantity of feathery hairs, causing the plant to have received a third popular name, "Old Man's Beard," which is also given to the long hairy pedicels of the abortive flowers of *Rhus cotinus*, common in good gardens, and admired for these curious tufts, and for its rosettes of bright green leaves, which remain till sharp frost comes.

Thistles, groundsels, and many other plants of the same family, have a hairy "pappus" attached to their seeds, thus enabling them to be carried by the wind to some distance. They are occasionally borne to a considerable height, and the air is full of them. This appeared to be the cause of a curious appearance noticed by the writer one day, a few years since, when looking through an astronomical telescope in one particular direction. The sky seemed to swarm with pale, glittering, falling bodies, like a meteor shower, and there was reason to believe they were of the nature of thistle-downs glancing in the sun.

Hairs contributing to the beauty of flowers may often be found on their petals; musk and heartsease supply examples. In some plants the hairs attract

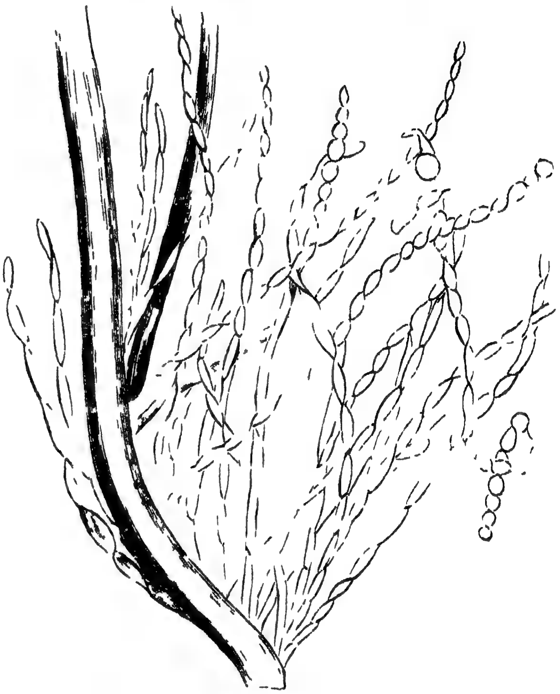


Fig. 4.—Portion of Filament of *Tradescantia Virginica*, with a few of the Hairs. (*Magnified 13 diameters.*)

insects by their secretions, and the insects carry the pollen from one plant to another, and thus fertilise them. Plant-hairs were found by Mr. Wenham to exhibit, at one portion of their existence, the movement of fluids in their cells, often miscalled "circulation." To see this phenomenon, the hairs should be selected in an early stage of their growth, removed without injury, placed in a drop of water under covering glass, and viewed with a one-eighth, or higher power of the microscope. In Mr. Wenham's hands it was difficult to find exceptions to this cell-rotation, whether he examined hairs from the highest elm or the humble weed. Sometimes the currents of the fluid are single, at others several occur in the same cell, having their point of departure from a little mass of "protoplasm" called a nucleus. With a microscope of sufficient power, and careful illumination with the instrument known as an "achromatic condenser," a quantity of minute granules may be seen moving with the fluid. Hairs cannot, however, be recommended to beginners, or indeed to any one who wishes to make sure of

seeing this cell-rotation. The part of a plant in which it is most likely to be seen is a leaf of *Elodea Canadensis* (*Anacharis alsinastrum*)—an American plant common in many of our ponds and rivers—selecting for observation a portion that has turned a little brown, and is more transparent than the rest. It is a mistake to compare this fluid motion in cells with the circulation of the blood in animals, or to confound it with the rise of fluids from the roots, and the preparation and diffusion of sap. It is a local matter, and in the case of hairs only slightly connected with the general growth of the plant. A still more remarkable function is performed by the so-called "hairs" of the Sundew (*Drosera*), or the Fly-Trap (*Dionæa*), and other flesh-feeding plants (p. 240); but as this has already been sufficiently described, we pass on to the last kind of hairs we shall mention, namely, those which do not naturally belong to plants, but result from parasites. The swellings on roses, conspicuous for their red hairs, and called Bedeguars, the hairy spangles on oak-leaves, and many others, are only growths determined by insects pricking a particular part and laying an egg there, and perhaps injecting an irritating fluid. Hairy formations of this sort thus have in their origin a resemblance to the galls on oak and other trees produced by species of Cynips. A whole group of mites—relations of spiders, and eight-legged, in complete development—are called gall-mites, from their egg-laying and excrescence-producing on various leaves. Lime-trees are commonly attacked in this way, and their leaves then exhibit dozens of stout hollow hairs. The same may sometimes be seen on vine-leaves and many others. The irritation caused by the insects or mites has an effect analogous to the cause that determines the production of hairs in natural growths. When the hairs occasioned by the mites widen out towards the base they are called "trumpet galls," and the creature is developed from the egg they inclose.

# A PIECE OF SLATE.

By H. Alleyne Nicholson, M.D., D.Sc., F.L.S.

*Regius Professor of Natural History in the University of Aberdeen*

In the year 1877, about 600,000 tons of slate were raised in the Principality of Wales, of which the huge and celebrated excavation of Penrhyn Quarries alone supplied between 80,000 and 90,000 tons. In Scotland and the Lake District of the North of England perhaps 150,000 tons were raised in the same year; and the amounts produced in North America, Belgium, and other countries where slate is worked, would probably form with the above a grand total of not far short of 1,000,000 tons. Six hundred years ago, the use of slate was confined to districts where the material was so abundant and conspicuous that its value could hardly be overlooked. Nowadays, slates are transported to all parts of the country by rail, road, and canal; and distant regions purchase large supplies of this valuable rock. The principal use made of the great quantity of slate now annually dug out of the earth, is to cover the roofs of our houses, a function which it discharges better than any other known material; but it is also employed in making the beds of billiard-tables, writing-slates, &c.

For all the various purposes for which it is used, slate owes its adaptability to the fact that it is capable of being split into thin layers or plates. So conspicuous, in fact, is this feature in slate that the term "slate" is in common language applied to all rocks which can be split into layers so thin that they can be used in roofing a house. In reality, however, many of the materials used in roofing houses are not *slates* at all in the scientific acceptation of the term. In many parts of the country, thin *flags*, or "tile-stones," are habitually used instead of slate; and though these look like thick slates, their true nature is really very different. In all these cases the flat surfaces of the slab are the surfaces of the successive layers of mud or sand out of which the rock was originally composed. As such layers are always comparatively thick, "slates" of this kind are much heavier than true slate, and thus compel builders to have recourse to high-pitched roofs and heavy timbering. Moreover, they do not stand the weather so well as true slates, and are thus in the long run more expensive than the material whose name and function they have usurped.

True slate, then, is a special and peculiar material, which not only splits into thin layers, but possesses various distinguishing characters, which

enable us to separate it from other rocks which at first sight appear to resemble it. In order to understand these characters, we should provide ourselves with a small piece of Welsh or Scottish roof-

Fig 1.—Penrhyn Slate-Quarry. (*After Horace B. Woodward.*) From a Photograph

ing-slate, and a small fragment of ordinary "shale," such as every native of a coal-district knows so well. Two such pieces of rock placed side by side are very like one another. Both probably are some tint of grey, blue, or black; both split easily into thin layers; and, what is more important, both show themselves to be nothing more than hardened mud, since both, if pounded down in water, give rise to a clayey ooze. These are striking and weighty points of resemblance, but they are accompanied by less conspicuous though fundamental points of dissimilarity, which make the difference between "shale" and "slate," and which we must briefly enumerate and consider.

"Shale," as any geologist will tell us, is nothing more than hardened and consolidated mud, originally accumulated at the bottom of the sea or of a lake, and now converted into rock. Vast quantities of mud are carried down into the ocean by rivers when in flood, and all of this at last finds a resting-place at the bottom of the sea. As the supply of mud is intermittent and periodic, it follows of necessity that the resulting accumulation on the floor of the sea is composed of successive layers, such layers being thicker when the mud is brought down in great quantity, and thinner when the supply is less abundant. The *quality* of the mud is, also, not invariably and at all times the same. Sometimes it is more or less largely mixed with sand; sometimes it may be intermingled with minute particles of decaying vegetable matter; or at other times it may be reddened by the presence of iron. Moreover, the mud, in accumulating on the sea-bottom, is very likely to entomb any animals, such as shell-fish, which might happen to inhabit the sea at that particular locality; or it might contain the leaves of plants or the branches of trees, or even the bones of land animals, brought down by the flooded river.

Now, such a deposit of mud as we have here supposed to be formed in the sea, when hardened and compressed forms "shale," and the peculiarities of this rock are simply those due to the method in which it was formed. Thus, if we look at a bed of shale, or even at a single small piece of it, we find that it is conspicuously made up of thicker or thinner layers. That these layers are the *original* layers of mud, thrown down one by one and at successive periods on the sea-bottom, is sufficiently shown by the fact that they often differ from one another more or less in grain, that they may be differently coloured, and, still more, by the fact that we often find between them the shells or skeletons of marine animals or the leaves of plants.

One point more remains to be mentioned, as showing the method in which shale is formed, and it is one which can only be shown by means of the microscope. If, namely, we take a little bit of shale, and grind it down to such a thinness that it becomes transparent, we can bring the microscope to bear upon it, and we can investigate with precision the very minute particles of which it is composed. When we do this we find that shale (Fig. 2) is composed of very small particles or grains of clay, and sometimes other mineral substances, which vary in size, and which are usually more or less rounded or irregular in outline. We find, further, that these particles are arranged without any definite order, the larger grains being promiscuously mixed up with the smaller ones, just as we should expect, if we recollect that shale is

formed by the slow sinking of mud and clay suspended in water.

Let us now turn from "shale" to "slate," and shortly consider the points of likeness and unlike-

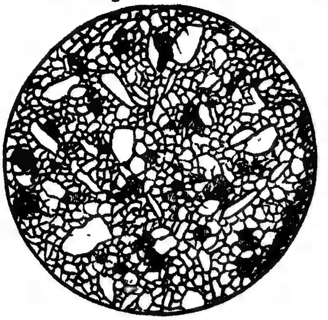


Fig. 2.—A Slice of Shale, viewed under the Microscope, and highly magnified.

ness between them. Ordinary slate, like shale, is hardened mud, and there is no doubt whatever that it was originally formed in the same way, namely, as a deposit of fine clayey ooze accumulated at the bottom of the sea. There is no doubt whatever of this, but the proofs of it do not lie at the surface, and are, therefore, not very easily recognised. If, however, you take a piece of Scottish or Welsh slate, or, better still, if you go to a slate-quarry and look at the rock upon a large scale, you will be able to see that slate is composed of alternating layers of mud, of different thicknesses and of different grain. Very often, also, there is a difference of colour in these different layers, giving rise to what is called the "stripe" of the slate. That these differently grained and differently coloured layers represent the original layers of mud, as successively deposited on the ocean bed, is proved to conclusiveness by the fact that very often—in some slates, at any rate—you may find lines of shells or other fossils running along these layers and corresponding with them.

So far, then, slate and shale agree with one another, and this is sufficient to prove that they are essentially the same, and that they were originally formed in the same way. At this point, however, we have to face a difficulty, which appears to be almost an insuperable one, and in which lies the fundamental distinction between slate and shale. If we look at our piece of shale, we see at once that the differently grained and differently coloured layers of which it is composed are all *parallel with the flat surfaces of the fragment* which we are examining. It is along the line of these layers that the shale splits if we apply force to it; and if any shells or other fossils are present in the fragment, they are found in layers which are also parallel to its upper and lower surfaces. On the other hand, in a piece of slate we find all this reversed. We find the same alternating *laminæ* of varying grain and colour; we sometimes even find the same layers of fossils; but all these now *run at some angle, often at right angles to the flat surfaces of the slate.* The slate no longer splits along these alternating layers; in fact, it usually strongly resists violence applied to it in a direction corresponding with these; but it will now split almost indefinitely in a direction which cuts these layers at a greater or less angle. This singular difference in the behaviour and structure of slate as compared with shale is diagrammatically shown in the annexed sketch (Fig. 3); and as this is the distinguishing peculiarity of slate, we must consider this point at greater length.

Admitting, as we must do, that slate and shale are essentially the same, in so far as they were

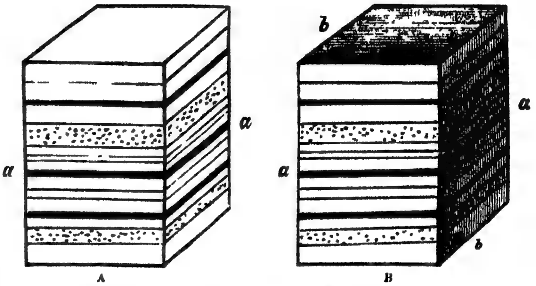



Fig. 3.—Diagram showing the different Modes in which Shale and Slate split. (A) Block of Shale, showing on its face and sides the differently grained and coloured Layers (*a*, *a*), along which the Rock splits. (B) A similar Block of Slate, showing the same Layers (*a*, *a*), along which the Rock will now *not* split, and which only remain on the face and sides of the Block as Lines of varying texture, the Block now splitting along the planes indicated by the fine Lines on the side and top (*b*, *b*).

formed the same way, and were, therefore, to begin with, identical, it is clear that something has happened to the slate by which it has assumed its present peculiarities. The characters of the shale are such as we should expect it to have when we know its mode of origin; whereas the slate has certain new and striking peculiarities. The slate, therefore, is neither more nor less than shale which has been *altered* in some way since it was originally formed. The conspicuous feature of this alteration, as we have seen, consists in the fact that the layers of mud composing the slate have generally become firmly amalgamated with one another by cohesion, at the same time that they preserve their distinctness due to difference of grain or colour; while new lines of weakness have been developed, in virtue of which the slate now readily splits into thin layers which intersect the original *laminæ* at

varying angles. To this capacity for splitting into plates, which have no necessary correspondence with the original layers of the rock, geologists have given the name of "cleavage." Slate is a "cleaved" rock, and its flat surfaces, or any planes parallel with these, are the so-called "cleavage-planes."

Great labour has been expended in the endeavour to supply an adequate explanation of the nature and mode of origin of "cleavage." We find this peculiar structure affecting not only an individual piece of rock or a single bed, but an entire tract or district, it may be hundreds of miles in length, and developed not only in the hardened mud which constitutes "clay-slate," but also in other rocks, such as limestone, sandstone, or volcanic ashes. The well-known "green slates" of Cumberland and Westmorland are "cleaved" volcanic ashes, and though heavier than the Welsh slates, they nevertheless exhibit the slaty structure in great perfection. As a rule, however, cleavage is most perfectly developed in the fine-grained mud-rocks; and in rocks of coarse texture the cleavage-planes generally become remote and irregular. Hence, when we find beds of clay alternating with beds of sandstone, the former may be beautifully cleaved, while the latter may be quite free from traces of cleavage. In such cases, however, the sandstones will generally show evident signs of having been subjected to great pressure. Without entering further into details of this kind, there are one or two important facts connected with the development of cleavage upon a large scale, which cannot be passed over in entire silence. Foremost amongst these is the fact that while the area occupied by cleaved rocks in any given country may be a very large one, the general direction (the so-called "strike") of the cleavage is almost always parallel with the great lines of fracture and uplift, which can be shown on other evidence to traverse the region. This establishes, to begin with, a presumption that the forces which have been at work in raising the region (or its mountain-ranges) to their present elevation, are also those which have given rise to the cleavage. Again, while the trend or "strike" of the cleavage is generally tolerably constant in a given region, the direction in which the cleavage-planes intersect the rocks (the so-called "dip") is usually very variable. Under any circumstances, also, the cleavage-planes pay no attention whatever to the beds or "strata" of which the rocks may be made up. Whatever may be the position of the beds—however greatly they may be folded or twisted—the cleavage-planes preserve a more or less constant direction. Hence, in districts where the crust of the earth has been much bent and fractured, the cleavage-planes often intersect the "stratification" at all angles, as will be readily understood by reference to the annexed diagram (Fig. 4), where the strong lines represent the folded beds or strata, and the fine lines indicate the direction of the cleavage-planes. Thus, at the point marked *a*, the cleavage-planes cross the original strata nearly at right angles, whereas at *b* they approximately coincide with the lines of bedding. The disregard

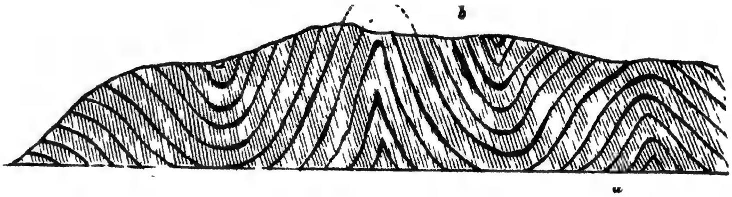



Fig 4.—Diagram showing Cleavage-Planes, as represented by the fine Lines, crossing a curved and folded Series of Strata

of the original lines of stratification shown by the cleavage is a clear proof that the cleavage-planes were developed *later* than the lines of bedding. First, the rock was laid down in successive beds or strata in the sea, and then it was subjected to some force which more or less completely welded together and sealed up these beds, and enabled it to split along a number of new lines. Lastly, we find that cleavage is most commonly and most perfectly developed in rocks of very ancient date; or, if it should be present in rocks of more modern age, it is only in cases where these rocks are now found raised to great elevations, or otherwise exhibit proofs of having been subjected to great pressure and disturbance. Thus the great slate-districts of Britain are North Wales, the Lake Country, and the Highlands—districts occupied by old Silurian or Cambrian deposits. Slaty cleavage is also very commonly a conspicuous feature in rocks belonging to the later period of the Devonian; and in the later, but still very ancient, series of the Carboniferous the same structure is often observable. The common occurrence of cleavage in old rocks raises a probability that the formation of slate is in some way due to mechanical pressure, for we have plenty of evidence that all the more ancient rocks of the earth's crust have been subjected to intense pressures and strains at different periods since the time of their first

formation. A similar conclusion is pointed to by the fact that fine-grained rocks of any age which can be shown to have been much compressed or folded, generally exhibit a more or less perfect slaty structure.

Not only have we the general probabilities above pointed out in favour of the direct connection between cleavage and mechanical pressure, but we have various facts which raise this probability to the rank of a certainty, and which further enable us to see *how* it is that pressure can produce cleavage. Perhaps the best way to arrive at an understanding of this subject will be to begin at the final link in the chain of proof, and to consider the effect of direct pressure upon a mass of clay. Such a mass, if mingled with any large-sized particles, such as scales of oxide of iron, may be taken as fairly representing the original and unaltered material of slate—viz., clayey mud with a variable intermixture of large-sized grains of sand, mica, &c. Let us now follow Mr. Sorby in one of his beautiful experiments, and let us subject this mass of clay to a pressure sufficiently great to reduce it, say, to one-half of its original volume. What results follow from this compression, apart from those of altered form and increased density? There are two very important and interesting results produced, as diagrammatically shown in the annexed sketch (Fig. 5). In the first place, the mass of clay

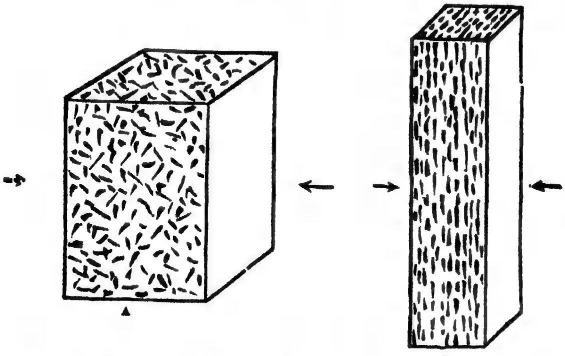
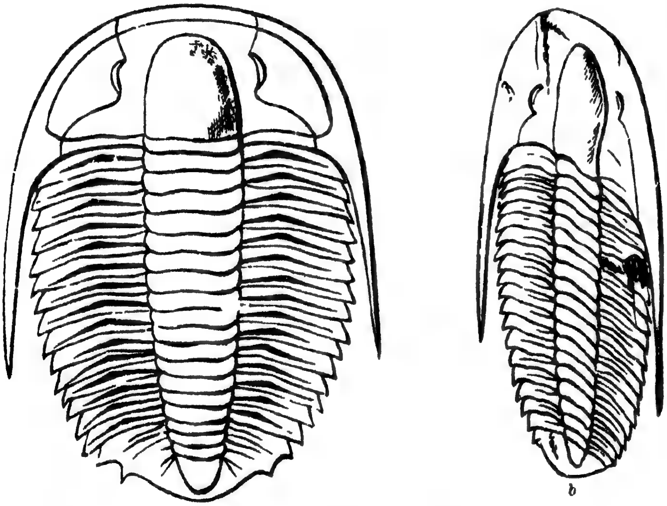



Fig. 5.—Diagram of a mass of Clay mixed with scales of Oxide of Iron before and after Pressure. (A) Shows the mass in its original condition, with the scales promiscuously scattered through it. (B) Shows the same mass after compression, with the scales arranged in Lines running at right angles to the Pressure, the Direction of the latter being indicated by the Arrows.

will now allow itself to be split into an almost indefinite number of thin layers, all of which are parallel with each other, and intersect the mass *in a direction at right angles to the direction in which the pressure was applied.* In other words, the clay is now "cleaved," and it has become converted into a true *slate.* In the second place, it will be found that the scales of oxide of iron, which were originally promiscuously scattered through the mass, have now assumed a new and definite arrangement. They have changed their original position, and have placed themselves with their flat sides facing the point from which pressure was applied. The long axis of each scale is thus directed now at right angles to the pressure, and hence the scales greatly conduce to the easy splitting of the mass in the same direction. It is not, however, necessary that elongated or scale-like particles should be present in the mass subjected to pressure, for, as Professor Tyndall has shown, perfect cleavage can be induced in pure white wax by the application of a sufficient pressure.

With the certainty that artificial cleavage can be produced by pressure, we have next to see if a similar cause can be held as accounting for the production of slate; and it is quite clear that we cannot accept such an explanation, unless slate shows phenomena essentially similar to those presented by such a compressed mass of clay as we have considered; that is to say, slate, if formed by pressure, *ought* to split or cleave in a direction at right angles to that in which the pressure was applied to it, and it ought to exhibit evidence that its particles have re-arranged themselves in such a manner that their long axes point in the same direction. As a matter of fact, both of the required proofs can be supplied, with more or less certainty. It is not, of course, possible to declare with absolute positiveness in what direction pressure may have been applied to any given mass or bed of slate. Still, there are many proofs that the pressure which has produced cleavage-planes in slate has been applied in a direction at right angles to these planes. Thus, the *strike* of the cleavage, as has been before mentioned, is generally parallel to the great mountain-ranges or geological lines of elevation in a country. Again, there is every reason to think that the chief forces which have caused foldings and crumplings of the earth's crust on a large scale, have been thrusts and strains developed in a direction *tangential on the whole to the earth's surface;* and this would account for the generally very high and often vertical inclination of cleavage-planes. Leaving such points, however, to the consideration of the professed geologist, we can easily show that slate fulfils the other required condition, in exhibiting a very marked re-arrangement of the minute particles of which it is made up. Not only does slate exhibit the clearest proof of its having been subjected to an intense *compression*—a compression which

seems to have been enough to reduce it to about one half of its original bulk, and which has conferred on it the high density and tenacity on which its commercial value largely depends; but we can also show that the particles of the rock have so far *changed their place* as to have disposed themselves *along the lines of least resistance.* This is readily shown by two phenomena of familiar occurrence in the slate-rocks. One of these is the constant, and to the scientific observer extremely vexatious, *distortion* in the shape of all fossils in a slate. All fossils, such as shells, are pulled out and *lengthened in the direction of the cleavage-planes.* This distortion is exhibited in the accompanying drawing (Fig. 6), representing the skeleton of an ancient Crustacean, termed a Trilobite, in its true shape and as distorted by cleavage. This phenomenon proves conclusively that there has been in the slate a kind of sliding



a b

Fig 6.—A Trilobite (*Angelina Sedgwickii*) in its natural Condition (*a*), and as distorted by Cleavage (*b*)

movement of the particles composing it, the movement taking place along the line of least resistance, or, in other words, along a line at right angles with the pressure, and therefore, necessarily, along the planes of cleavage. Not only are fossils drawn out in this way, but if the rock happen to contain pebbles (as is sometimes the case), it is found that these pebbles have undergone a similar re-arrangement, so that they are all disposed with their long axes coinciding in direction with the cleavage-planes.

Even when there are neither fossils nor pebbles in the slate—and in the best roofing-slates there are neither—we have, however, still the means of proving a similar re-arrangement of the particles of

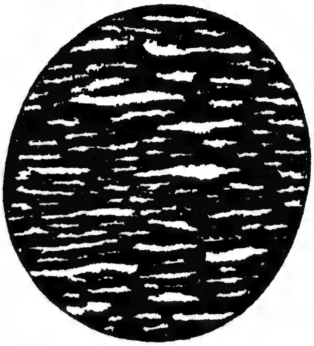


Fig 7.—A Fragment of Slate, cut into a thin Slice, and magnified highly.

the slate, if we have recourse to the microscope. If we look at a slice of slate ground sufficiently thin to be transparent, we find that all the longer particles of the slate are arranged with their long axes pointing in the direction of the cleavage-planes (Fig. 7), and therefore at right angles to the pressure by which the cleavage was caused. In the same way, all flat particles, such as plates of mica, are so disposed that their flat surfaces correspond with the cleavage-planes; and there can be no doubt that the perfection of the slate and the facility with which it can be divided into thin plates depends very largely upon this re-arrangement of the minute particles of which the rock is made up.

Upon the whole, then, there is an irresistible body of evidence in favour of the view that slaty cleavage is the result of the operation of intense lateral pressure upon fine-grained rocks. Sometimes, no doubt, the pressure requisite for the production of slate may be derived from some local source, of merely limited application. For the pressures, however, which are capable of converting large areas of rock into slate we must look to those mighty telluric forces which are developed as the result of reactions going on between the heated interior and the cooled exterior of our planet, and which are the efficient agents in the production of mountain-ranges in particular, and of dry land in general.

# A POND, AND WHAT IS IN IT.

By B. B. Woodward, F.G.S., etc.

"AS dull as ditch-water" is a good old English saying, carrying us back to a time when the study of natural history was a thing not dreamt of by our forefathers. No one in those days thought of impaling beetles (or "bugs" as all insects were then indiscriminately called) on pins, of arranging them in drawers, and calling it "entomology." In those good old days bats were blind, and toads spat fire; and he who dared to doubt it, or manifest any interest in the works of nature, was quickly suspected of being in league with the Evil One, and treated accordingly. With the advance of knowledge many of these old popular notions died out, and the invention of the microscope, and the subsequent improvements in it, gradually brought to light the fact that the duller and dirtier the ditch, the more it teems with innumerable minute living beings. The popular mind, nevertheless, still clings with limpet like tenacity to the old saw, and fails even yet to realise the importance of the discovery, either through sheer ignorance, or the want of a due appreciation of the works of nature. Next to the ditch, the pond seems, from the popular point of view, about the dullest thing imaginable; and yet both the microscopist and the naturalist hold that a pond is one of the finest "hunting-grounds" possible. The geologist, too, will, when consulted, testify that more may be learnt from half an hour's careful observation of what is taking place on the edge of a pond where a stream is running into it, than by many days' reading.

This, to be understood, must be put to the proof. The would-be naturalist must seek out the nearest pond, and there, on its banks, work out its history for himself.

The first point he will have to consider will be the apparently trivial question of "What is a pond, and how are ponds formed?" We say "*apparently trivial*" because it is in the careful reasoning out of seemingly simple questions such as these that some of the grandest laws of nature become clear to us.

Our naturalist probably settles in his mind that a pond is nothing more nor less than a hollow in the ground filled with water, and having disposed of that head, will find, as Hercules did in the Hydra, two others in place of it—viz, "Whence did the water come?" and "How was this hollow or depression formed?"

In response to the former question he will first call to mind how, when the rain is falling on soil into which it cannot soak, the water, seeking the lowest level, runs into the minor inequalities of the ground and forms puddles. Then arguing from the less to the greater that the bigger the hollow the bigger the puddle, he at length arrives at one sufficiently large to be dignified by the name of a pond. Ponds, again, range upwards in size, and finally merge into lakes (pp. 311—313).

To the second question our friend might urge that these hollows were merely due to the wearing and tearing action on the earth's surface of the various atmospheric agencies (already fully described at pp. 33—40 and 116—124), and that though the slope of the surrounding ground might be imperceptible to the eye, yet the water, unerringly obeying the law of gravity, has collected in this the lowest spot of all. To this we may add that a local subsidence, following on the removal by water of earth below the surface, may likewise give rise to a pond, as will also the formation of a barrier, whether natural or artificial, thrown across the valley of a stream. Since water-tightness is a necessity for their existence, and as, in nine cases out of ten, clay is the material that insures this qualification, it follows that ponds are most abundant on clayey soils; and not unfrequently do they indicate to the field-geologist the presence of this rock in places where it might not otherwise have been suspected.

When we have satisfactorily solved the question as to the causes that brought our pond into existence, we shall be at liberty to consider what is in it.

This we shall find is a less easy task, and can only be accomplished by paying a series of visits, at different times of the year.

The first thing that strikes the eye on approaching a pond is the thick green carpeting spread in patches over its surface. This carpet and the innumerable little floating plants that compose it are well known to all as the Common Duckweed. A figure of some of these plants—duckweeds—with their long roots, is given on p. 98.

There are two other kinds of duckweed to be found in England. One is very similar to the last, but the leaf is larger, with red under-surface; whilst the Ivy-leaved Duckweed is sufficiently described by its name.

Peeping out amongst the duckweed the lanceolate leaves of the Broad Pond-weed are to be seen; or, perchance, instead, the round ones of the Frog-bit.

Below the surface, the Water-milfoil and the Elodea form a vast subaqueous forest, thickly tenanted by water creatures.

This latter plant was first introduced into Britain from North America in 1847, but it speedily became so abundant as to have in some places impeded the navigation of rivers and canals.

With the plants of the pond, however, we have less to do at the present moment than the animals, and accordingly turn our attention in that direction, passing in brief review the more important examples.

In yonder sunny corner the surface of the water is kept in constant agitation by numerous small shining black specks moving in and out and round about each other with untiring activity. If this state of perpetual motion may be taken as a sign of

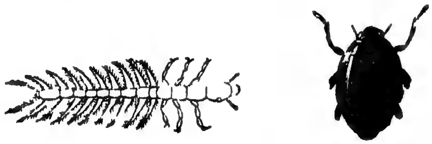


Fig 1.—Larva and Imago of Whirligig Beetle (*Gyrinus natator*).

its happiness, the Whirligig Beetle (*Gyrinus natator*—Fig. 1), for he it is, ought to be the merriest of the pond-dwellers.

There is a peculiarity in the structure of the eye of this beetle worthy of our notice. Each of these organs is divided by a longitudinal partition into two parts, which practically endows it with four eyes. Of these, one pair is directed upwards and keeps a sharp look-out for the approach of danger from that quarter; whilst the other, directed downwards, superintends the commissariat department.

The prey (small insects, &c.) is seized by the fore pair of legs, which are lengthened for that purpose, the two hinder pairs being modified into short and broad paddles, whereby the insect is enabled to perform its marvellous gyrations.

The lord over all the water-insects, however, is the big fellow now rising to the surface for the purpose of taking in a fresh cargo of air, which he carries between his wing-cases and body—they are all air-breathers, these water-insects, and as readily drowned as you or I. Having laid in an adequate supply, off he starts again in pursuit of fresh victims. Indeed, the water-creatures have no more formidable enemy than this same Plunger Beetle (*Dyticus marginalis*—Fig. 2), defended as he is from all attacks by a suit of armour, beside which the best ever worn by the most puissant of knights was clumsy in the last degree.

His weapons of offence consist of a most terrible pair of jaws, coupled with an array of suckers on the extremities of the first and second pairs of legs, so that, once in his grasp, the unlucky prey has not the slightest chance against its assailant.

Nor is the larva less voracious than the perfect insect; for, though a soft-bodied grub, it possesses a ferocious pair of sickle-shaped jaws, hollow from end to end, through which it sucks the juices of snails or any weaker brother it can seize. A pair of ample wings, mysteriously folded up under the wing-cases, are ready to bear the *Dyticus* from pond to pond at pleasure, or when compelled by a summer's drought to shift his quarters.

This beetle is one of a large family, and his cousins of various degrees of removal, and ranging downwards in size, are always to be found in the same situations and pursuing the same course of life.

Walking rather than swimming through the water, is a larger though far less powerful beetle—the great Water Beetle (*Hydrous piceus*—Fig. 4)—falling a prey at times, it is said, to its more active neighbour the *Dyticus*. In colour he is black, and in point of diet mainly a vegetarian, though the larva resembles that of *Dyticus* both in regimen and general appearance.

Abundant as are the beetles in every pond, they are rivalled, if not surpassed, in number by the "Norfolk-Howard" family. Most conspicuous of these is the Water Boat-fly (*Notonecta glauca*—Fig. 3), who may be seen floating at the surface of

Fig 3.—The Boat-fly (*Notonecta glauca*).

every piece of water, engaged, like the beetles, in taking in a fresh supply of air; but whilst the beetle is back uppermost, the bug prefers to swim with his back downwards—an arrangement which,

Fig. 2.—Metamorphoses of the Plunger Beetle (*Dyticus marginalis*).
The Male Beetle is on the wing; the Female is on the Surface of the Water.

however seemingly awkward from our point of view, is to the *Notonecta* an advantage, enabling it to attack its prey from beneath; a mode of assault which he is said to practise with success on even the small fish.

Unlike the beetles, too, the larval stage of the bugs is very similar to the adult, and individuals of all ages will be found together.

Still more plentiful is the nearly-allied *Corixa*, who can be easily distinguished from the Boat-fly, as he follows the normal mode of progression (*i.e.*, back upwards), and who descends from the surface as if going down a spiral staircase. The middle pair of legs are the longest, and are used as anchors, by means of which this insect may be observed holding on to the pebbles at the bottom, and giving at intervals a kind of spasmodic flip with his paddles. In amongst the weeds another kind (*Naucoris cimicoides*) will be found: a flat, oval, and rather soft-bodied little fellow.

By far the most curious-looking members of this interesting family are the Water Scorpion (*Nepa cinerea*—Fig. 5), and his first-cousin the *Ranatra* (*R. linearis*). The former owes his name to the large size of the fore-limbs, which are carried straight out in front, like the claws of his namesake, and to the presence of a bristle-like tail. The body is oval and not thicker than a sixpence; the middle and hind pair of legs are very slender, and by no means adapted for swimming; hence he dwells amongst the thick weed, seldom venturing into clear water; but, relying on his close similarity to a dead leaf, awaits with open arms the advent of the foolish water-creature that shall first pass within reach.

The only thing in which, at first sight, the *Nepa*

appears to resemble the *Ranatra*, is the bristle-like tail. This, in reality, consists of two bristles placed close together. Down the inner side of each there runs a groove, so that when in juxtaposition they form a fine tube leading down to the cavity between

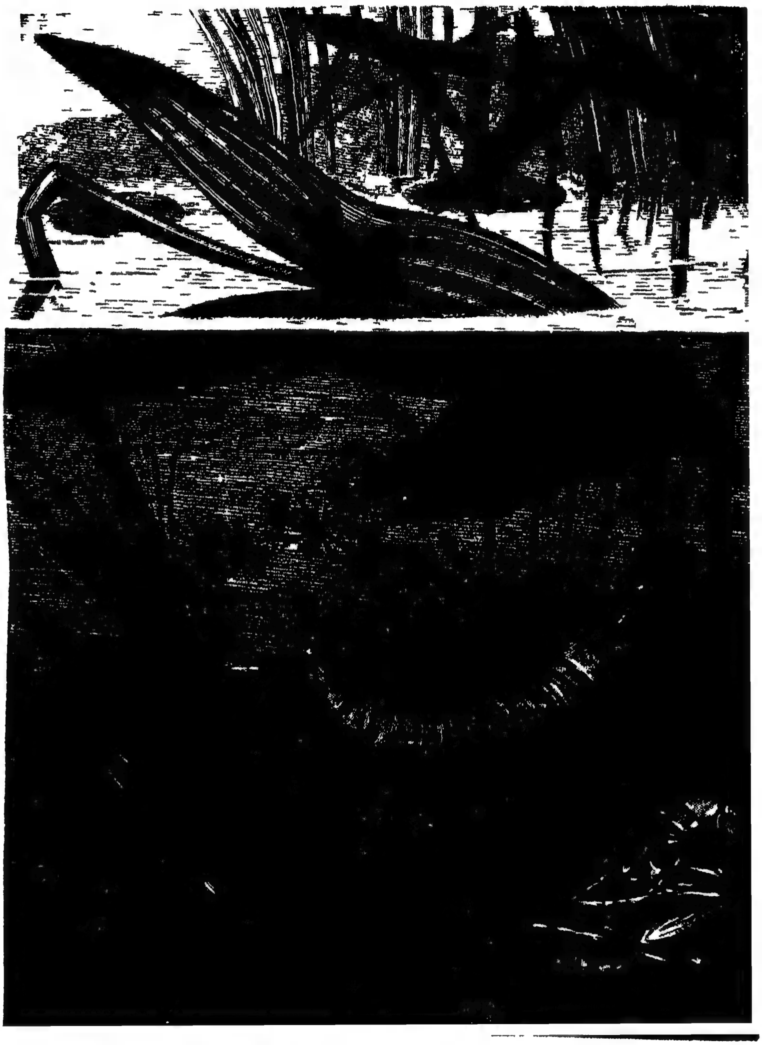


Fig 4.—Metamorphoses of the Great Water Beetle (*Hydrous piceus*).

the wings and the body, and the creature can therefore obtain a fresh supply of air without coming quite to the surface, by simply extending the tip of this tube above the water. In other respects, they appear very different, the *Ranatra* being as long and cylindrical as the *Nepa* is broad and flat. Closer inspection proves the difference to be in degree, rather than in kind; and the more narrowly we compare them, the more does the somewhat ludicrous notion seize us that originally they were identical, and were subsequently altered, the one by being passed under a mangle, whilst the other was pulled through the keyhole.

Skimming over the surface is another lanky individual, the Water Boatman (*Gerris paludum*); whilst near the margin the most elongated of them all (*Hydrometra stagnorum*—Fig. 6) may be found crawling on the aquatic plants and decaying vegetation.

Besides the foregoing, so to speak, permanent residents, there are some insects that spend a portion only of their existence under water. The common gnat is a familiar example of this class to

which also the May-fly and Dragon-fly (Fig. 7) belong, all three passing the larval and pupal stages under water.*

But it is time for us to pass from these rapacious individuals, to speak about some of the more peaceful denizens. Gliding along at the surface of the water, shell downmost, we observe several different kinds of pond-snails. The commonest of these is the "Wandering Mud-snail" (*Limnæa peregra*), which is not only widely distributed—occurring throughout Europe, and ranging into Siberia and Tibet—but also most subject to variation according to the surrounding circumstances in which it is placed. Indeed, it is not impossible that the local form known as the Ear-shaped Mud-shell (*L. auricularia*) may be merely a very expanded variety of this same "Wanderer," though not yet acknowledged as such by authorities. The finest of our fresh-water molluscs is the Pond Limnæa (*L. stagnalis*), whose spiral shell measures nearly two inches in length, two-thirds being taken up by the last, or "body-whorl," as it is called. He is a famous aquarium glass-cleaner, but has an unfortunate habit of dying in some out-of-the-way corner of the establishment, the first announcement of his decease being the unwholesome state of the water.

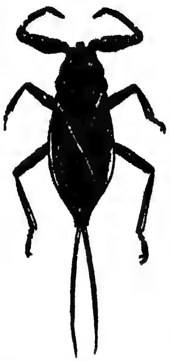


Fig. 5.—The Water Scorpion (*Nepa cinerea*)

*Fig. 6.—Hydrometra stagnorum.*

In all the Limnæas the shell is very thin, semi-transparent, and horn-coloured; and the external surface, especially in *L. stagnalis*, looks as if it had been hammered all over. Then there is the fresh-water limpet (*Ancylus lacustris*), and the Coil-shells (*Planorbis*), varying in size from that of a half-penny downwards, in which the shell, instead of being spiral, is wound upon itself like a watch-spring.

Crawling on the bottom is yet another snail, of very different appearance; proportionately shorter and dumpier than the Limnæas of a greenish-yellow tint, with brown bands. The peculiarity of this genus (*Paludina*) is that the eggs are hatched within the shell of the parent, the young escaping at about the end of two months.

If we descend into the mud at the bottom, the "fresh-water cockles" (*Cyclas* and *Pisidium*), and possibly the fresh-water mussels (*Anodon* and *Unio*), will also await us. The *Cyclas* "draws out" of the mud during the summer months, and may be found climbing the water-plants, or floating near the surface.

That delight of juvenile anglers, the common three-spined stickleback (*Gasterosteus aculeatus*) is sure to be present in all his glory. Nor is he to be despised; he has a scientific fame, is a nest-builder, and not only does he build the nest, but also, arrayed in a coat of many colours, watches over and defends it against all comers, with a courage unequalled in one of his small size.

Here also is the Great Warty Triton (*Triton cristatus*—Fig. 8), with black-spotted orange waistcoat; and his lesser relative, the common newt (*Lissotriton punctatus*); whilst the eggs and tadpoles of the common frog and toad may be had in abundance during the spring months. The life-history of the newts and frogs is a study in itself, as has already been shown (p. 81, etc.).

It would take a volume to describe the water-spiders, water-mites, leeches, and myriad lesser fry that people the subaqueous forest; and he who would make himself even superficially acquainted with the fauna of a pond, must arm himself with a good net, and attack the creatures in their weedy stronghold. A net on a long stick will do a great deal, certainly. The surest method of proceeding is to detach the net from the stick, and fasten it by four short cords to the end of a stout line, and then, having weighted the end of the net with a bullet or two, and lined it with gauze to prevent the escape of the small specimens through the meshes, hurl it right out into the middle of the pond, and drag it to shore through every possible patch of weed. The "net" result should then be shaken out on a level spot on the bank, the quarry captured, and specimens taken home for the purpose of identification and study.

By proceeding in this wholesale manner, specimens that might otherwise escape get dragged in and secured.

A careful examination of the gauze lining should

* A most amusing account of the two last-mentioned is given in Kingsley's "Water Babies;" and a short but graphic description of the metamorphoses of the Dragon-fly has already appeared in these pages, together with figures of the different stages (pp. 76, 77).

ɢ. 7.—Metamorphoses of Dragon-flies.

be made between each haul, as small specimens, such as water-mites and minute larvæ, are sure to be found sticking to it.

At present we cannot do more than dip a wide-mouthed glass bottle into the water where the weed is thickest, and hold it up to the light to see if any of these lesser inhabitants are present.

There are some little whitish creatures skipping about with a jerky motion that has earned for them the name of water-fleas. They claim no relationship, however, to the *Aphaniptera*, being in reality crustaceans of the genera *Daphnia*, *Cyclops*, &c., and are interesting as microscopic objects. Two or three water-mites, looking like small hairy-legged spiders, with red bodies, complete the list of visible animalcules. The rest must wait till we get home.

But stop! What are these green specks roving at will through the water? The *Volvox globator*, or moving vegetables, so sought after by the microscopists. It is rather capricious in its choice of locality and times of occurrence, and should therefore be secured whenever found, as it is one of the most beautiful objects imaginable under the microscope.

Had we suspected its presence here, we should have certainly mentioned it with the other pond plants; still, better late than never.

Another point of interest in connection with our subject deserves to be mentioned. Supposing a new pond to be formed at some distance from any previously existing piece of water, how is it that before very long it becomes thickly populated? and what forms are likely to arrive first? Now, the air we breathe is full of small specks of dust called motes, as may be seen when a ray of sunlight is shining into a room. Many of these specks or motes are nothing more than the germs or eggs of the thousand and one animalcules so prevalent in all waters. As soon as ever these germs alight on water, development commences, and the matured individuals, by their rapid multiplication, speedily stock the new-found situation with life. The

g 8—The Great Warty Newt (*Triton cristatus*) · Male, Female, and Tadpole

insects, of course, find their way thither on the wing. The beetles, especially *Dyticus*, are great nocturnal fliers, plunging down at cock-crow into the nearest piece of water; hence their occasional presence in water-butts, or the durance vile of a roadside puddle. The newts and frogs, too, will travel by the overland route; but how do the snails get there? This has been answered by Mr. Darwin, who suspended the feet of a duck in an aquarium, where the eggs of fresh-water shells were hatching. Some of the young snails crawled on to these feet, and adhered so firmly that they could not be jarred off, though readily falling at a more advanced age. These young molluscs when taken out of the water survived in damp air from twelve to twenty-four hours, during which period a long journey could be made by the bird. The same observer also mentions that a *Dyticus* was caught with an *Ancylus* firmly adhering to it; and were any one to take the trouble of intercepting these beetles during their nocturnal excursions, they would doubtless be found to play an important part in thus distributing the smaller species of water-creatures. The transference of fish from place to place, without calling in the aid of the before-mentioned juvenile angler, is, however, a question that does not admit of easy solution at present. The seeds of plants, on the other hand, may be transported in many ways.

Enough has now surely been said, in even this brief space, to show that a pond, so far from being as devoid of interest as most people seem to consider, is, in reality, an inexhaustible source of both amusement and instruction. Amusement in watching the—to us, at all events—curious behaviour of its inhabitants, either in a state of nature or when kept in an aquarium; instruction, in systematically studying these various beings collectively, or as separate members of the animal kingdom: or, when we consider their distribution, the abundance of some particular species in one locality, and its variety or absence in another; or its prevalence at one season of the year and scarcity at another: or again, in ascertaining the effect on them of the presence or absence of mineral matter, such as lime, iron, &c., in solution in the water, with many other questions of a like nature too numerous to be detailed.

From the foregoing remarks it may be gathered that ponds are interesting—Firstly, in themselves, their presence being due to physical causes, not merely in operation at the present day, but also in remote bygone ages; secondly, on account of the various forms of life they contain. These alone are a life-long study, embracing as they do representatives of most of the zoological sub-kingdoms, from the back-boned amphibians down to the lowest forms of animal life, where they pass almost imperceptibly into the vegetable world; whilst researches into their habits, economy, structure, distribution, &c., marshal before one a host of interesting questions, and numerous as yet unsolved problems.

## THE CANDLE-FLAME, AND SOME OF ITS LESSONS.

By R. Gerstl, F.C.S.

There are few phenomena in nature so wonderful as the flame of a candle, or—what is, as we shall presently see, essentially the same—the flame of an oil-lamp, or of gas, or of the burning coal in our fire-places. Yet who pays any particular attention to it? Very likely that "familiarity," which is responsible for so much neglect, has to account also for this indifference.

We will try in these lines to awaken the reader's interest in this subject by bringing before him briefly the chief points necessary for an understanding of the process of visible combustion; and by hinting, still more briefly, at some of the important conclusions which result from the study of that process.

Any piece of candle will do to begin our observations with. We select one of wax on account of its cleanliness. I may take it as generally known that the material is a secretion of the bee. On allowing our specimen—say one of which twelve go to the pound—to burn for awhile, we notice that it diminishes in size; and we know that after a certain number of hours the whole of the candle will have disappeared, short only of an insignificant remnant which ceases to burn because the little stump of wick will drop out of its place. Well, what has become of the candle? has it been destroyed?—that is, has it become *nothing?* To receive an answer to this question we shall resort to the balance. This is an old instrument—we find it

already on Egyptian bas-reliefs; but its application in the investigation scientific problems is of comparatively recent date. Its introduction into chemical research forms a landmark in modern science. We will place a small piece of our wax candle on a perforated cork (*a*, Fig. 1), fit it into one end of the cylindrical glass tube, now push into the other a piece of wire-gauze (*b*), so as to form a kind of netting, and place into this latter lumps of caustic soda. A copper wire, fastened round the glass tube in the manner seen in the diagram, permits the whole contrivance to be hung at one end of the beam of a suitable pair of scales (Fig. 2). After having balanced it, the cork is taken out, the candle on it is lighted, and the cork now quickly put back into the tube. In a few minutes—four or five—the beam-end carrying the glass tube will descend.* What does this mean? Nothing less than that the candle in the course of burning increases in weight. Whence comes the substance which adds to the original weight of the candle, and what is this substance?

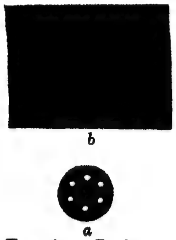



Fig. 1. — Perforated Cork (*a*) and Wire-Gauze (*b*).

Before we pursue further this question, we must

Fig. 2.—Showing Increase of Weight in a Burning Candle.

first know which part of the candle is really the source of the flame. If we scrape some chips of wax off the candle and heat them (Fig. 3) in a teaspoon over the flame of p rhaps another candle, the wax will melt, emit fumes, and these soon

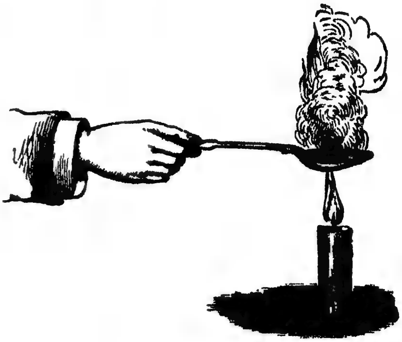


Fig 3.—Decomposition of Wax by Heat.

burst into flames, which resemble closely that of the candle. If, on the other hand, we take a piece of dry lamp-wick and light it, we shall get a flame barely able to maintain its life. We see then that it is the wax which feeds the flame, and that the wick's function is merely to convey by suction the molten wax to the region of the flame, where it is converted into vapours, just as in the heated spoon.

And now, why does the candle increase in weight during burning? Is anything else feeding the flame besides the wax? We know we are surrounded by a substance called air, and it is a common experience that the presence of this agent is indispensable in the burning of our light and heat giving materials. Let us place a piece of burning candle into a bottle and close the mouth with a cork. In a few minutes the candle will extinguish, and we shall notice that the inner sides of the bottle are covered with a film of moisture. On pouring some clear lime-water † into the bottle, we observe that the liquid becomes turbid. and after standing awhile deposits a fine white powder.

Here we must make some slight digression. In 1774 Joseph Priestley had discovered that by heating a red powder, in those days called calx of mercury, a gas ‡ was obtained, in which combustible bodies burned with great brilliancy—indeed, in which materials incapable of burning in the ordinary air, like a piece of steel wire, did so with intensity in the new air. Very shortly after him, Lavoisier, a great French chemist, found that by heating

* Some little care is required in the execution of this experiment, but details of manipulation may be omitted in a popular exposition.

† Lime-water is prepared by shaking up a little slaked lime with water, and, after allowing it to settle, pouring off the clear liquid from the sediment.

‡ *Gas* is a scientific name for aëriform bodies. It is derived from *Geist*, the German for "ghost."

metallic mercury for a sufficiently long time in an inclosed space of air, the metal was transformed into red calx of mercury, that this weighed more than the original metal, that the increase in weight was due to a fixing of a portion of the air in which the metal had been heated, and, finally, that the remaining portion of the air, which was incapable of supporting the burning of a candle, weighed exactly by so much less as the mercury had gained in weight. This portion of the air has received the name of *oxygen.*

We commence now to guess why the candle in our experiment had increased in weight. As in Lavoisier's experiment the mercury fixes the oxygen of the air, so does in this case the vapour of wax. But to arrive at a complete understanding of the process, we must acquaint ourselves with the properties of two substances of which the wax of the candle is principally made up, and which in burning are transformed into those bodies that are retained by the caustic soda in the experiment with the balance.

By pouring a mixture of water and hydrochloric acid on some pieces of zinc, a gas will be evolved, which proves to be combustible. On trying this experiment in a flask closed with a cork (Fig. 4), into which a long thin glass tube is fitted, a steady little flame may be obtained. On holding a tumbler over this flame we notice the appearance of moisture, and if we use an arrangement as shown in Fig. 5, we are able to collect a sensible quantity of the liquid, which is the product of the combination of the oxygen of the air with the gas issuing from the bottle, and proves to be water. The gas has been called *hydrogen,* of which Greek word the equivalent in English would be "water-generator."

Fig. 4.—Evolution of Hydrogen.

It will now be quite correct to conclude that whenever water is formed during the combustion of some substance, there must be hydrogen present in the burning material; and chemical analysis has really shown that wax—as, indeed, the great mass of animal and vegetable matter—contains hydrogen.

But there is something else formed during the burning of the candle. It was mentioned above that on shaking up the air in the bottle in which a piece of candle was allowed to burn until it extinguished, with clear lime-water, a white powder is formed.

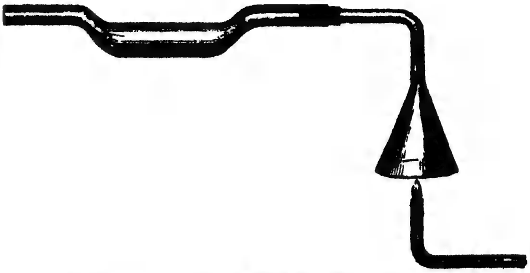


Fig. 5.—Apparatus for collecting the Water formed in the Burning of Hydrogen.

Now, on burning a piece of charcoal in a current of air, and passing the gas obtained into lime-water, we obtain the same white powder. The gas is a combination of the carbon which has burnt away, with the oxygen of the air, and has been called *carbonic acid.* Here, too, we shall be correct in concluding, that whenever carbonic acid is produced in the combustion of a substance, there must be carbon contained in that substance. Thus we infer that wax must contain carbon, since it yields, during burning, carbonic acid. In like manner, if the gas resulting from the burning of colza oil, or paraffin oil, or coal-gas, or coal itself, is passed into lime-water, we obtain proof of the formation of carbonic acid.

This is the place to observe, that caustic soda, a substance obtained from the ordinary soda so much used in households, possesses the property of absorbing carbonic acid, and, to a certain extent, also of retaining moisture. It was on account of these qualities placed in the upper part of the glass tube in which we burnt the candle for the purpose of showing the increase in the weight of the burning candle.

If we collect the white powder formed by passing carbonic acid into lime-water, and put a drop of vinegar on it, we notice that it effervesces—that is, that it evolves some gas. Supposing we did this in such a manner as to be able to pass this gas into lime-water, we should obtain the same white precipitate as before. We have therefore our carbonic acid back, and that, too, in a pure state, not admixed with such parts of air as were unconsumed in the burning of the charcoal.

It is worth our while to study some of the properties of this gas. But in order to obtain it in larger quantities we employ white marble and hydrochloric acid, it having been found that the

former contains carbonic acid. We shall employ an apparatus as shown in Fig. 6. The large bottle with the funnel-tube contains the marble and the acid; the smaller one, directly joined to it, is filled with oil of vitriol for drying the gas, oil of vitriol possessing the property of abstracting moisture from bodies it comes in contact with. On pouring some muriatic acid, diluted with water, down the funnel-tube, the evolution of carbonic acid will at once begin. If we fill a tall jar

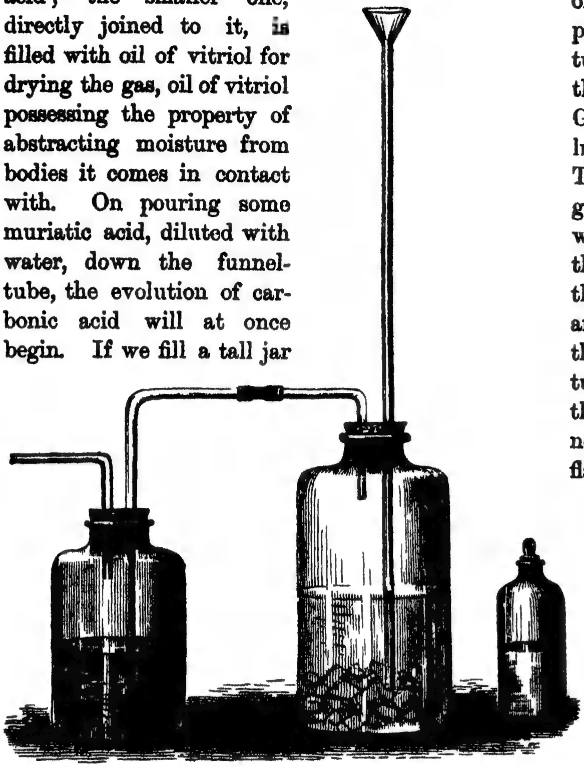


Fig 6.—Apparatus for preparing Dry Carbonic-Acid Gas

with the gas, we find that a burning candle introduced into it is extinguished. If we fill a glass beaker, which had previously been balanced (Fig. 7) on a suitable pair of scales, with carbonic acid, the pan containing the beaker will be seen to sink. The heaviness of the gas can also be shown by pouring it, like an ordinary liquid, from one vessel into another, and then lowering a burning candle into the latter (Fig. 8).

That which applies to a candle, applies also to the flame of an oil lamp or to a gas flame, or, indeed, to the flame of any of the materials commonly used for lighting and heating; in all these cases water and carbonic acid are the chief products of the combustion.

As the atmospheric air surrounds the whole earth, it is natural that combustible gases, like coal-gas, or the gas got by heating wax, &c., should burn in the air; but this is no necessary condition of burning. Should an atmosphere of coal-gas envelop our globe, a jet of what now constitutes the atmosphere would burn equally well. This may be shown by a very simple arrangement.

A chimney-glass (Fig. 9), such as used in an ordinary paraffin lamp, is provided with a twice perforated cork; through one of the holes a straight tube, of about ½ inch in diameter, passes; through the other a bent one (*b*), of perhaps ¼ inch bore. Gas is allowed to enter through *b*, and after being lighted the chimney-glass is fixed upon the cork. The gas-supply is now increased until the flame, gradually vanishing, at last leaps over to the air which enters at the wider tube, being drawn in by the draught. On lighting the gas which issues at the top of the chimney-glass, ocular evidence is afforded of an atmosphere of coal-gas surrounding the air-flame. On introducing through the wide tube a narrow one (*a*), and conducting coal-gas through the latter, we obtain the interesting phenomenon of a coal-gas flame burning in an air-flame.*

The inhalation of air in our breathing has been known for ages past. But it was only since the process of combustion had been understood that the chemical part of breathing had been fully ascertained. We know now that the oxygen of the atmosphere is conveyed through the lungs to the blood (p. 218), and that the exhaled air contains water, in the shape of vapour, and carbonic acid. Surely, this absorption of oxygen and emission of carbonic acid and water seem to be the same process as the burning of the wax candle? But whence come the carbon and the hydrogen required for

Fig 7—Illustrating the Heaviness of Carbonic-Acid Gas.

the formation of those two substances? The answe given by chemistry is, that it comes from the food

* The success of these experiments depends very much on good proportions in the width and length of the tubes; but

which we take, and which is composed chiefly of carbon and hydrogen, combined together in the most different proportions. A burnt slice of toast,

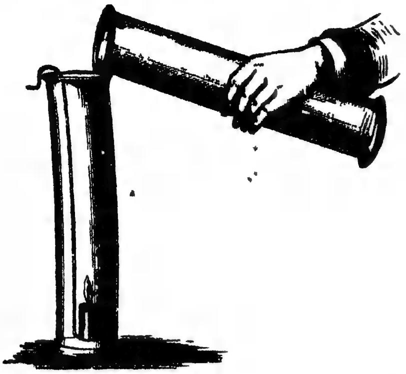


Fig 8.—Pouring Carbonic-Acid Gas from one Vessel to another.

a charred mutton-chop, are familiar demonstrations of the existence of carbon in these articles of food. The presence of carbonic acid in the air given out by our lungs may easily be demonstrated by *blowing* through a glass tube (*a*) into a bottle (Fig. 10) with lime-water: the appearance of turbidity will give us the desired proof. If we *draw* through tube *b* air into the liquid, no turbidity will ensue.

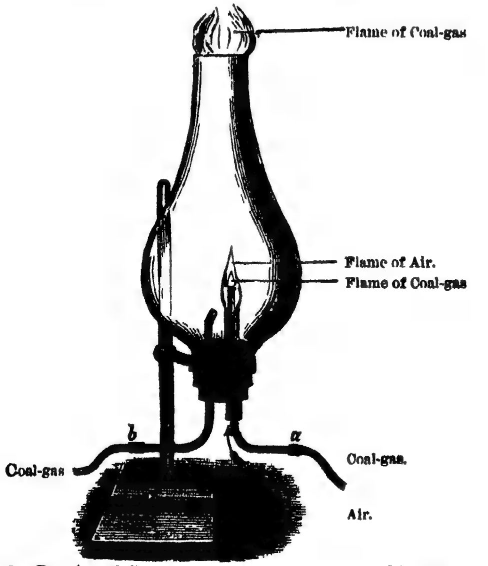



Fig. 9.—Burning of Common Air in an Atmosphere of Coal-Gas.

It was stated that carbonic acid is unable to support combustion; it has to be added, that it is equally unfit for breathing, and, from the analogy of the processes of burning and breathing, we can conceive that it must be so. But it is not only

details of this kind need not be given here, from reasons already

that carbonic-acid gas by itself is detrimental to the continuation of both processes; the admixture of a certain proportion of it to the ordinary air is capable of bringing about the extinction of a flame or of life. Now, since we produce continually carbonic acid by breathing and burning, it becomes necessary to pay attention to the renewing of the air in our dwelling-rooms and other inclosed spaces.


Fig. 10.—Apparatus for detecting Carbonic Acid in the Air expired by the Lungs

It was stated above that carbonic acid is heavier than the atmospheric air; we would therefore conclude that the carbonic acid evolved by breathing, and lights, and fires would accumulate at the floor of the rooms. But this is not the case; carbonic acid, when warmer than the surrounding air, ascends. We may make this evident by placing a stand (Fig. 11) carrying three burning pieces of candle, fixed at different heights, under a bell-jar. That the candles will extinguish we know; but on this occasion we shall also see that the topmost candle dies first, the middle one next, and the lowest one last.

If in this experiment we provide for an inlet of fresh air (the rough edge of the bell-jar, not touching the table everywhere closely, offers sufficient means for this), no change in the course of the process will take place. But if we arrange the bell-jar so as to allow the

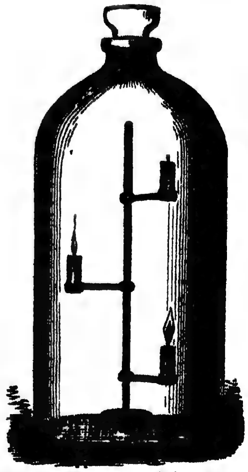


Fig. 11.—Experiment for showing that heated Carbonic-Acid Gas ascends.

in Fig. 12, whilst at the same time fresh air is admitted, the combustion will continue. One of the candles in the experiment represented in Fig. 12 is placed a little above the lower end of the outlet tube; it will soon go out, because the carbonic acid, accumulating at the top of the bell-jar, has to surround it before it reaches the opening of the tube.

The fact that heated air—and the carbonic acid of our lungs is always warmer than the surrounding air—pro-

duces a current of air, is utilised in ventilating public places, &c., as explained in a previous paper (p. 218). This principle is illustrated in the above experiment: the vitiated air is allowed to escape near the top, and the fresh air is admitted near the floor. In ordinary dwelling-rooms, the fire-place and the chimney form the ventilating channel. But here we must stop, for satisfactory treatment of the question of ventilation is beyond the scope of this article.

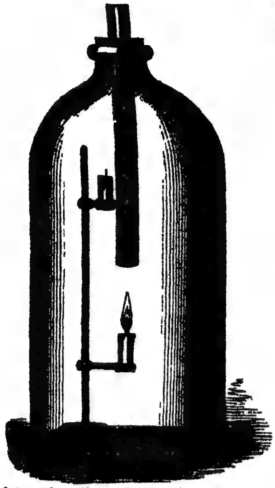


Fig. 12.—Experiment for Showing that if the Carbonic-Acid G allowed to escape at the Top, the Candle will continue to burn.

The amount of carbonic acid in the atmosphere is from 3 to 4 parts by bulk in 10,000 parts of air. A fairly ventilated room will contain 6 parts in the like quantity of air. But how far certain places have been from such a desirable condition may be seen from the following data, obtained some years ago by Dr. Angus Smith, of Manchester:—

| | Parts of carbonic ε 10,000 of air. |
|---|---|
| Chancery Court, 7 ft. from ground, closed doors . . | 19·3 |
| " 3 ft. " " . . | 20·3 |
| " door wide open . . | 5·0 |
| Strand Theatre, gallery, 10 p.m. . . . . . . . . | 10·1 |
| Surrey Theatre, boxes, 10 p.m. . . . . . . . . | 11·1 |
| " " 12 p.m. . . . . . . . . | 21·8 |
| Standard Theatre, pit, 11 p.m. . . . . . . . . | 32·0 |

The authority just quoted recommends a very easy method for ascertaining the extent to which the air in rooms is vitiated with carbonic acid. The method rests on the fact that a certain minimum quantity of carbonic acid is required to cause a visible precipitate in half an ounce of clear lime-water. If two quantities of air give with half an ounce of lime-water the same amounts of turbidity, it naturally follows that actually the same amount of carbonic acid is contained in both samples; and if the relative bulk of the one to that of the other were, say, 1 to 2, the former would contain twice as much carbonic acid as the latter. If less than 6 parts of carbonic acid are contained in 10,000 parts of air, a bottle, holding about 10½ ounces, filled with such air would give no precipitate with half an ounce of lime-water; and our rooms should be kept in such a state of ventilation.

We turn now to the external appearances of the flames. Looking attentively at our burning candle, we notice that its flame (Fig. 13) forms a

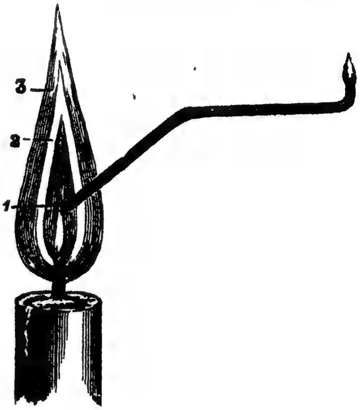



Fig. 13.—Different Zones of Flame, and Combustibility of the Gases of the innermost Flame

cone, rounded at the base, and consisting of three shells, or zones—the innermost (1), around the wick, appears dark; the one next to it (2) is bright yellow, and luminous; and the outermost (3) is a thin bluish wrapper, not very luminous. The central zone contains the vapours and gases arising respectively from the evaporation and decomposition of the molten wax drawn up by the wick. That there is really no combustion going on in this zone may be shown by quickly thrusting a common lucifer match into the candle flame in such a way as to have the phosphorus tip resting in the dark zone, when it will be seen that the wood will be charred where it comes in contact with the outer burning shell. By taking instead of a candle a gas-burner, which, in consequence of having air admixed with the gas, gives a non-luminous flame (Fig. 14), the hollowness of the flame-cone may be demonstrated in some striking ways. Thus, if we insert for a moment into the broadest portion

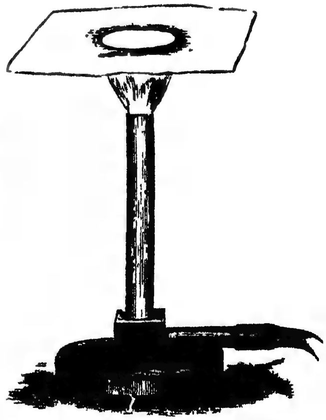


Fig. 14.—Showing the Hollowness of Flame-Cone.

of the flame a strip of folded blotting-paper, it will, on being withdrawn, present the appearance shown in A, Fig. 15, and, if the paper be unfolded, look as in B. Another proof is that represented in Fig. 14, where a piece of stout white blotting-paper is pressed down upon the flame, when soon a brown ring will indicate the burning portion of the flame. That the gases in the dark zone are combustible may be made evident by inserting into the candle-flame one end of a bent glass tube (Fig. 13), and setting light to the vapour issuing at the other end.

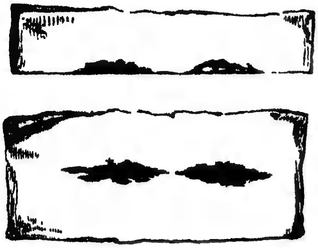


Fig. 15.—Another Experimental Proof of the Hollowness of a Flame.

The second zone is, as we stated, the real source of the light the flame emits, and the luminous character is generally ascribed to the presence of very finely-divided carbon, which is raised to whiteness by the heat evolved in the oxidation of a portion of the gases. The occurrence of the carbon is due to the fact that the combustible gases have not sufficient oxygen in the second zone for complete combustion, and that therefore the carbon separates out. By holding a piece of card-board paper over a candle-flame, we obtain the carbon in the shape of soot, and by scraping off the latter and throwing it into a non-luminous spirit-flame, we produce scintillation. The explanation that the carbon separates out in consequence of insufficient supply of oxygen is supported by the phenomenon of a luminous gas-flame becoming non-luminous when air is admixed with the gas previous to its being light.

But though these instances are strongly in favour of the view that the luminosity of a flame is due to the incandescence of solid bodies, there are cases known of flames which give a bright light, and yet have no solid particles dispersed in the flame. Hydrogen, of which it was mentioned above that it burns with a pale flame, will yield a luminous flame when burning under an increased atmospheric pressure.

In the third, the outermost zone, the combination between the combustible gases and the oxygen of the air takes place in a complete manner.

Our task is done. We know now what is required to produce a flame, and what the nature of a flame is. We have also, in passing, seen how close an analogy there is between combustion and respiration, and how this leads to the subject of ventilation.

But, for an exhaustive comprehension of the process of burning, one more question remains to be answered. Why do the carbon and the hydrogen obtained from the decomposition of the wax produce, when uniting with oxygen in our optic nerves, the sensation which we call light?

At present we possess no clue whatever to this marvellous phenomenon; so complete, indeed, is our ignorance, that we have not even a gleam of hope of ever penetrating into this mystery.

## IRIDESCENT GLASS.

By William Ackroyd,

*Member of the Physical Society, London.*

AMBER and emerald, purple and turquoise blue, are some of the hues exhibited on a specimen of the clear white glass to which the name of iridescent or rainbow-tinted has been applied. It is not a rainbow, however, that it calls to mind, so much as the finest-formed of soap-bubbles, for at the sight of it we feel the same surprise, make the same conjectures, and are inclined to form the same wild theories that we indulged in years ago, when blowing soap-bubbles for boyish amusement.

Can the glass ornament have something in common with the soap-bubble? And if there be some community of structure, how has it been impressed upon the iridescent glass to make it so unlike all other glass-ware; in other words, to what discovery in the glass-manufacturer's art are we indebted for these pleasing ornaments?

It has long been known that if glass be exposed for a great length of time to the action of the atmosphere, its surface is chemically acted upon, and a substance which we are accustomed to regard as the most durable, so far as resistance to the action of moisture is concerned, will in time become entirely changed. By this chemical action, thin plates or *laminæ*, are formed on the surface of the glass, and these thin plates are the physical cause

of the variety of tint displayed by glass which has been "weathered" in this way. The fact of iridescence resulting from long atmospheric action on glass was, according to Brewster, observed by Lord Brereton in 1666; and in recent times specimens of decomposed glass have been found among the ruins of Assyrian, Greek, and Roman buildings, exhibiting in exquisite perfection tints so brilliant as to far surpass any colours producible by art.

Stable windows are peculiarly liable to this change, because of the action of the ammoniacal vapours to which they are exposed.

The subject has been experimentally studied by several Frenchmen. M. Meunier has exhibited a glass that had been made iridescent by being subjected to the action of vapours arising from certain volcanic ashes, and MM. Frémy and Clémandot have attempted to make iridescent glass in a regular manner by submitting various kinds of glass to the combined action of heat, pressure, and weak acid. Clémandot has patented this process in France, England, and America, and it is his iridescent glass which now may be seen in the windows of most glass-warehouses, and which forms the subject of the present paper.

As we have before observed, a thin transparent film is formed by chemical action on the surfaces of the vases, bowls, and cups of glass, and we shall have to inquire how this pellucid film acts upon light to produce so many colours. As a first step, let us see whether a thin transparent film is necessary in other cases to produce the same phenomenon.

Prepare a pretty strong lather of soap, and blow into it with a tube—as, *e.g.*, the stem of a clay pipe. A crowd of bubbles arise, and each bubble is formed of a film of soap solution, transparent, and so exceedingly thin as to burst very readily. The film exhibits iridescent colours.

In making a bulb at the end of a glass tube, as described in a former paper (p. 108), one sometimes blows too hard; the bulb bursts, and an exceedingly thin filmy mass of glass is produced. Here, again, iridescent colours are exhibited.

In the neighbourhood of gas-works, one may sometimes see large gorgeous tracts on the surface of the river or canal passing by, which result from tarry matter having spread over the surface of the water in an exceedingly thin film—so thin as to be transparent. Here, too, the colours, which one has only to see to admire, arise from the tenuity and transparency of the tarry film.

This last example reminds us of a patent taken out years ago by the Messrs. de la Rue for ornamenting stationery, &c. In their process, the objects to be ornamented, whatever they may be, are immersed in water, upon the tranquil surface of which a little oil or spirit-varnish is afterwards dropped. The varnish, spreading out in all directions, soon becomes extremely thin, and exhibits the most vivid colours. When the varnish is fixed, the object is slowly raised so that the film will adhere to its surface; it is then dried, and a permanent iridescent film is in this manner made to beautify its surface.

My friend Professor S. P. Thompson has lately published a recipe for preparing iridescent films that are permanent. He takes about 54 per cent. of Canada balsam, and 46 per cent. of amber-coloured resin. When this mixture is sufficiently fused, say at a temperature of 90° to 95° C., frames constructed of thin brass wire are dipped into it. Films of the fused mixture adhere to the wire, and exhibit permanently the usual colours, if carefully and slowly cooled.

From these facts it is very evident, then, that these remarkable tints are produced by very thin plates of transparent material, and on this account scientific men speak of the appearance as *the colours of thin plates*. Nor is it necessary for these plates to be liquid or solid, as in the examples so far given, for we can get the phenomenon with a thin film of air. Let the reader make the following experiment: Procure two pieces of plane glass, not too thick, as in that case they are not sufficiently flexible. In fact, to make the experiment easily and to one's entire satisfaction, it is better to employ for one of the plates a piece of the thin glass used by microscopists for covering objects. Place such a covering glass flat on a piece of clean window-pane, and press upon it gently with the point of a pencil. All round the pencil point there will be formed a number of concentric coloured rings. To see them, the eye must be placed so as to catch the light at a large angle of reflection. This is the phenomenon known as "Newton's rings," and it is produced by the thin film of air which exists between the two plates of glass. Fig. 1 is intended to give an idea of the experiment, where the covering glass *b* rests upon a piece of window-pane *a*, and around the pencil point the coloured rings are formed.

Another remarkable fact is seen in this experiment. That a plate of glass is not perfectly smooth is often evident to the unaided eye; parallel *striæ*, flecks, and bubbles, being seen on it with ease.

This uneven nature of the surface may aid the common house-fly in walking up window-panes; but let that be as it may, when two plates of glass are placed flat on each other, as in the experiment just described, these two plates are in contact only at a very few points, which may be comparatively far from each other. When, therefore, we press down the end of a pencil on the surface of the upper plate, directly under the pencil point the two glass plates are probably in contact, and their distance apart increases on all sides in leaving this spot; in other words, the film of air between them is of variable thickness, being thinnest where the plates are in contact, and augmenting in thickness outwards from this point on all sides. But on leaving the point of contact and proceeding outwards, we have, likewise, several series of different colours. Putting the two things together, the idea dawns upon us that *the colour of a thin film varies with its thickness.*

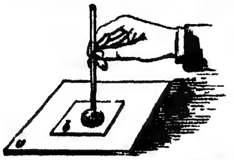


Fig. 1.—Showing how Newton's Rings may be produced.

We may conveniently make a stand here to think over the few facts so far described, and to try if possible to give them their place among the colour phenomena we have studied in former papers. In the first place we may assert that the iridescence we are studying is not a case of the analysis of light, arising from dispersion, as described in the article on "The Rainbow" (p. 192). For when light is broken up in the manner there described, we require a wedge of the substance—*i.e.*, a piece of the transparent material with two opposing faces inclined to each other, in order to effect this breaking up of light; whereas, in this phenomenon of thin plates, the opposing faces of the film may be perfectly parallel. Nor is it a case of *Selective Absorption*, such as that described in the paper on "The Colours of Animals" (p. 251), because, as we have seen, many of the substances with which we can get the colours of thin plates are colourless when we examine the light which has passed through them. This singular phenomenon of thin plates is therefore neither due to absorption nor to dispersion as we at present understand those terms.

All this may be applied to the consideration of the iridescent glass. Observation of it alone would have taught us little, but by gathering information from every available source, by careful comparisons, and by much thought, we can say of it, that by Clémandot's process a very thin plate of variable thickness and transparent material is formed on the surface, that this thin plate acting upon light like a thin film of air or soapsuds, decomposes it somehow, and gives rise to the amber and emerald, purple and blue, and the host of other tints observable on its surface.

We have now to seek for some scientific explanation of the phenomenon, and again we shall have to utilise the light scattered from many a source and converge it in one strong beam on the subject in hand.

We have already seen that many things which are true of wave-motion as we see it in water, likewise hold good for motion of the luminiferous ether (pp. 189, 191), and when we look into the matter more closely, the analogy which subsists between the two classes of phenomena is seen more strikingly still.

A stone thrown into water produces a series of waves which emanate from the point of disturbance in ever-widening rings. As Chaucer hath it—

> "*If that thou*
> Throw in water now a stone,
> Well wottest thou it will make anon
> A little roundel as a circle,
> Per'venture as broad as a covércle;*
> And right anon thou shalt see weel
> That circle cause another wheel,
> And that the third, and so forth, brother,
> Every circle causing other
> Much broader than himselfen was."
>
> *House of Fame.*

Similarly, an atom of matter made to move about violently, by heating intensely the substance to which it belongs, will disturb the ether around it, and so send out waves on every hand which, when they reach the retina and disturb it, give the sensation of light. The retina is so delicately formed, moreover, that it can "feel," as it were, differences in the quantity and quality of this ethereal wave-motion. The longest ether-waves to which it is sensitive produce the impression of redness, and the shortest, that of violet light. The intermediate colours which one obtains in a spectrum—*i.e.*, orange, yellow, green, blue, and indigo, are between red and violet in wave-length. As the result of exact measurements, we know that the mean length of a wave of red light is $\frac{1}{39000}$th of an inch, and the mean length of a wave of violet light $\frac{1}{57500}$th of an inch.

As we are discussing questions which lie outside of the ordinary subjects of conversation, and therefore require a new vocabulary to be drawn on, we must now explain a few terms usually employed

* *i.e.*, Pot-lid.

in discussing these matters. Let w w′, Fig. 2, represent the water-level, and the wavy line *a b a′ b′* the outline of a series of waves produced by dropping

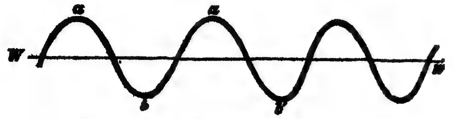


Fig. 2.—Illustrating Wave-Motion.

a stone into water, then the elevations of water *a a′* are called *crests*, while the depressions *b b′* are termed hollows or sinuses; and the length of a wave is measured from the top of one crest to the top of the next one, as, *e.g.*, from *a* to *a′*, or, what amounts to the same thing, the distance from the one hollow to the consecutive one, as from *b* to *b′*. We may now continue our comparison of wave-motion in the two media, water and luminiferous ether, or rather what we see in the former we may picture in the mind's eye as occurring in the latter, and thus explain some of the remarkable things in light that we have here to deal with.

Instead of one, now throw at the same moment two stones on to the surface of the still water. Two systems of waves are produced, and they very soon meet at a point in the straight line which joins the centres of disturbance. Where the two sets of wave-rings meet, one of two things may happen; either—

(1) Crest may coincide with crest, and hollow with hollow, and give us crests and hollows of double height and depth at the place of meeting; or—

(2) The crests of one system may coincide with the hollows of the other, and give us no wave at all at the place of meeting.

How one wave may *interfere* with another, as in (1) and (2), is better seen after considering the part an individual water-particle takes in the wave-motion. A cork placed on the surface of the water simply dances up and down when the wave passes; therefore, the water-particles which carry it simply dance up and down, and they do not travel along with the wave. The wave is consequently only a travelling *form*, and is produced by the communication of motion from one set of water-particles to another. When a wave meets another, and is in complete accordance with it, as in (1), the wave resulting is formed, as it were, by the super-position of one on the other; for the water-particles would have been carried to a certain height and depressed to a certain depth if only a single wave had passed the meeting-point at a given moment; and when another passes at the very same instant, a double force is exerted on the water-particles; they are carried to a double height and depressed nearly to a double depth.

On the other hand, when one wave reaches the

Fig. 3.—The Accordance of Waves.

meeting-point half a wave-length before the other, or lags behind half a wave-length, crest is made to coincide with hollow, as in (2), and at the point of meeting a water-particle is constrained to go up, and it is equally constrained to fall down. Between the two there is little, if any, motion at all. The first condition of things is represented by Fig. 3, where

Fig. 4.—The Discordance of Waves.

the waves *a* and *b*, being in accordance, produce the form $(a + b)$. The second condition of things is represented by Fig. 4, where *c* and *d*, being in complete discordance, give us the result of their mutual action on each other $(c + d)$—*i.e.*, no wave at all.

Such phenomena go under the general name of *Interference*, and in whatever medium waves are produced, we may have such a mutual action of one set on another. In air, *e.g.*, the sound-waves producing two notes slightly out of unison, will interfere with each other and give us "beats"—*i.e.*, a succession, more or less rapid, of sound and silence. Again, in the luminiferous ether among the multitude of waves which produce white light, under certain conditions some may interfere with each other to the extinction of certain coloured rays, and thus give us the colours of thin plates. The latter fact we must now enlarge upon.

It may be stated generally that whenever a ray

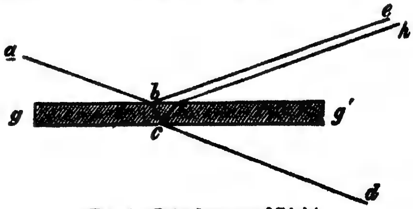


Fig. 5.—Interference of Light.

of light is bent by passing from one substance into another, a portion of that ray is reflected back. The ray *a b*, Fig. 5, in passing from air into the denser medium plate-glass (*g g′*), is partly reflected

in the direction $b\ e$; and the remainder of the light passes forward in the direction $b\ c$. Again, where the portion $b\ c$ passes from the glass into air, a part of it is reflected within the glass in the direction $c\ f$, and a fractional part of this takes the direction $f\ h$. The ray $b\ e$, reflected from the first surface of the glass, is parallel to the ray $f\ h$, arising from reflection at the second surface. Now imagine the thick plate of glass to be gradually decreased in thickness, until its width is no more than one-quarter the length of a wave of light, say one-fourth of $\frac{1}{30000}$th of an inch—*i.e.*, $\frac{1}{120000}$th—and suppose, moreover, for convenience of calculation, that waves of red light are $\frac{1}{30000}$th of an inch long, and waves of violet light $\frac{1}{60000}$th of an inch in length, then under these circumstances we may expect the following events to happen when a ray of white light ($a\ b$) falls on such a plate ($g\ g'$).

The reflected rays $b\ e$ and $f\ h$, with the common source $a$, being exceedingly near to each other and parallel, are favourably placed for interference. Now, it so happens, that when a ray of light is reflected in the endeavour to pass from one medium to another much denser, its waves are retarded half a wave-length, a fact which has its perfect analogue when we come to consider the transmission of motion from one system of particles to another larger and heavier. Hence, the ray $b\ e$, which is reflected in the endeavour of $a\ b$ to pass from air into glass, has lost *half* a wave-length in the act of reflection. The violet portion of the ray $f\ h$, on the other hand, has lost a *whole* wave-length, for the distance from $b$ to $c$, and thence to $f$, is, roughly speaking, equal to the length of a wave of violet light ($\frac{1}{120000} \times 2 = \frac{1}{60000}$). The violet constituent of $b\ e$ is half a wave behind, and the corresponding portion of $f\ h$ a whole wave-length behind. There is complete discordance; crest coincides with hollow, and they mutually destroy each other. The violet light is quenched.

We may now consider the rays of the opposite end of the spectrum. The waves of red light in $b\ e$ are retarded half a wave-length in the act of reflection, just as the violet waves are; but the thickness of the glass plate bears a different relation to the length of a wave of red light. From $b$ to $c$, and thence to $f$, $\frac{1}{60000}$th of an inch, is only half the length of a wave of red light, $\frac{1}{30000}$th of an inch. Hence the waves of red light in $b\ e$ and $f\ h$, being all half a wave behind, are in perfect accord—crest coincides with crest, and hollow with hollow. The red light is intensified.

We see, then, that a plate of glass an inch in thickness quenches the violet end of the spectrum and intensifies the red end; consequently the colour of such a thin plate will probably be a rosy red. Here we have a colour produced neither by dispersion nor by absorption, but by interference of the ether-waves; and from what we have so far said it will be evident that every variation of thickness, within certain limits, will produce a variation of tint. In support of the latter point we have already adduced facts respecting "Newton's rings," and we may here devote a few words to the explanation of that phenomenon.

In the experiment we are about to describe Newton used *monochromatic* light—*i.e.*, light of one colour. Such light may be obtained by salting the wick of a spirit-lamp, or by putting an iron spoon containing common salt into the flame of a Bunsen burner. The light is bright yellow, and if we were to pass it through a prism we should obtain no rainbow-coloured spectrum, but simply a band of one colour—yellow. The other apparatus he employed will be understood upon reference to Fig. 6, which likewise represents the method now generally employed for obtaining "Newton's rings." Two lenses, one (A A′) a double convex, and the other ($a\ a'$) a plano-convex, are placed together, so that the plane face of the latter may be in contact with one of the convex sides of the former. They are now pressed together by means of the screws, and Newton's rings are produced. By employing monochromatic light, Newton obtained, instead of iris rings, an alternation of bright yellow and dark rings; and the thickness of air-film producing them, he ascertained by calculation, having first procured the requisite data—diameters of the rings and curvature of the convex lens. His results, with the modern explanation of the appearances, may be put in this form:—

Fig. 6.—Apparatus for producing Newton's Rings.

| Half wave-lengths the li[illegible] flected second of the air-film. (1) | Half wave-lengths lost [illegible] the passage [illegible] the ray through the air-film and back | Total loss in half wave-lengths. (3) | Nature of rings. |
|---|---|---|---|
| | 0 | | Dark circle. |
| 1 | 1 | | Bright ring. |
| 1 | 2 | | Dark " |
| 1 | 3 | | Bright " |
| 1 | 4 | | Dark " |
| 1 | 5 | | Bright " |
| 1 | 6 | | Dark " |

Column 1 gives the retardation of one half wave-length, which takes place when light is reflected in the endeavour to pass from one medium to another that is denser—in the present case from air into glass.

The reader will readily see that column 2 is obtained by taking twice the thickness of the air-film at the place referred to in column 4, and expressing this in half wave-lengths of the monochromatic light used. For example, the first bright ring is formed according to Newton at a thickness of air-film of $\frac{1}{178000}$th of an inch; and twice this, or the distance through the film and back, is equal to one-half a wave of the kind of light he employed.

Now, pay particular attention to column 3, and it will be seen that wherever the retardation is an odd number of half waves, there we get a dark ring, for we have discordance. On the other hand, wherever the retardation is an even number of half wave-lengths—*i.e.*, a number of whole wave-lengths—there we obtain a bright ring, for we have complete accordance.

It will be as well for the reader to repeat the experiment which forms the subject of Fig. 1 in a dark room, employing yellow light instead of any other kind. To this end, it is only necessary, as we have already pointed out, to salt the wick of a spirit-lamp, or hold common salt in the Bunsen flame. The alternation of bright and dark rings will then be seen.

From all that we have said, it appears that Clémandot's iridescent glass is one out of many examples of that phenomenon, noticed first by Boyle, then by Hooke, and afterwards by Newton in a much more complete manner, and known as "the colours of thin plates."

# THE CHEMISTRY OF THE DINNER-TABLE.

By Professor F. R. Eaton Lowe.

When the readers of these pages were good enough to join us early one morning at breakfast, the chemical relation between the food which appeared on our table, and the tissues of the human body, was pointed out; and the principal organic compounds essential to the complete nutrition of those tissues were described in detail. It was further shown (p. 271) that, if we wish to have a "sound mind in a sound body" the selection of our food must not be left to mere taste or caprice, but that we ought to be guided in our choice by a reference to the nutritive character of such food, and by an estimate of its adaptability to meet the requirements of the entire system. If it is necessary to exercise a judicious discrimination in the selection of the food which is to be served up at breakfast, the importance of such a course becomes augmented when we have to deal with dinner, for that is, *par excellence*, the meal of the day. It is the meal to which the humblest as well as the highest look for their chief supply of life-sustaining and strength-supporting nourishment, and in the preparation of which all the resources of the *cuisine* are brought into requisition, and all the skill of the cook called into play. It is at dinner that the labourer enjoys the only portion of animal food he can usually secure during the day; it is at dinner that the gourmand commits the greatest havoc with his constitution by his excess; and it is at the same meal that the epicure, who regards gastronomy as the only science deserving the attention of the human intellect, gratifies his fastidious palate by a long succession of highly-seasoned dishes, whose complicated flavours constitute, in his vitiated judgment, their principal excellence. The epicurean devotee seldom goes to any great lengths at breakfast. After a hot supper on the previous evening he rises at ten with a headache, and complains of disinclination to eat. To serve him up a steak or mutton chop would be as tantalising as to offer a cigar to a victim in the throes of sea-sickness. In a few hours his morning languor wears off, unless he is hopelessly dilapidated, and he is ready for what he terms a "good" dinner, but which, as we shall presently find, is really an atrociously bad one. Its excellence is measured by the number of courses of which it consists; so that a dinner of six courses is popularly considered to be just twice as "good" as a dinner of three; while, to have sat down to a repast of ten or twelve dishes, with a wine supposed to be specially applicable to each, is, in the opinion of most people, something to be proud of. The *rationale* of all this is sufficiently obvious. Neither the cook nor his patrons trouble themselves about the question of nutritiveness. The great object in the preparation of these long-drawn-out dinners is simply the production of a series of dishes which, by their piquancy and variety of flavour, shall

successively stimulate the appetite afresh after satiety has been reached. The mischief produced by this kind of intemperance is serious, and in the end irremediable. The physical discomfort experienced after indulgence in such meals is a significant indication of the constitutional derangement it is producing. In the refinements of modern luxuriousness we must seek for an explanation of our physical degeneracy as a race. In bygone ages, when, fortunately for the race then existing, civilisation was not sufficiently advanced to teach its members how to concoct, and how to eat, cunningly-devised sauces and ragouts, a healthier and hardier type of humanity prevailed. The Normans restricted themselves to two meals a day; well would it be for us in this age of boasted intellectual advancement if we were to follow their rule of life as laid down in the following old triplet:—

> "To rise at five, to dine at nine,
> To sup at five, to bed at nine,
> Makes a man live to ninety-nine."

It must be mentioned, however, that a Norman knight generally managed to spin out his dinner to three hours' duration. Rich soups, oleaginous gravies, and dainty "kickshaws," he would have disdained; but he took care that his table should be well supplied with beef, mutton, venison, boar's head, goat's flesh, and game. His digestion was too good to require stimulation by hot condiments, but he washed down his food with plenty of light wine from Bordeaux and Burgundy, and after his repast beguiled away another half-hour in sipping his *basset* and other beverages made of spiced wine and honey.

The Saxon regimen was somewhat similar, but these people were particularly fond of swine's flesh, which was never absent from the dinner-table, and they were despised by the Normans for their intemperate use of ale—a beverage which holds almost as high a place in the affections of the British public as it did a thousand years ago. In the time of the Tudors, civilisation began to make rapid strides, so that two more meals were added to the daily quantum; but still they had the good sense to keep early hours. They had breakfast at 7, dinner at 10, supper at 4, and a *livery* consisting of cakes and mulled wine or sack at bed-time. Coming down to our own time, we need not again refer to the heterogeneous mixture of solids and fluids partaken of at 6 or 7 o'clock, except to remark that the intemperance which marred the simplicity of the Saxon and Tudor periods seemed to produce less disease and physical deterioration than the luxurious living of our upper and middle classes in the present day, although we should be sorry to be understood as recommending a return to the mediæval habit of finishing a carousal by a comfortable nap under the table.

But let us proceed to ascertain what modern science teaches respecting the elements of a really "good" dinner. A table of the organic constituents of food has already been given in this work (p. 271). With the first two elements on the list—starch and sugar—we have little concern on the present occasion, unless our literary guests wish to make a dinner largely of bread. The next four compounds—*fat, albumen, fibrin*, and *casein*—are of considerable importance, and constitute together a complete heat-giving and flesh-forming source of aliment. Fat, albumen, and fibrin, are found combined in the flesh of animals; so that we have very good grounds for selecting animal food as our chief source of nourishment at dinner. Casein is the flesh-forming element in cheese, which may be, and often is, by the poor, substituted for meat at that meal. Albumen, which forms seven per cent. of the blood, and is found in large quantity in the nerves, brain, glands, and muscles, has already been fully described; we therefore pass on to *Fibrin*, which forms the solid portion of muscle or flesh, whether derived from quadrupeds, fish, or birds. When blood is left to stand for some hours, it separates into two portions—the *serum*, which remains fluid, and consists chiefly of water, and the clot or *crassamentum*, which solidifies, and contains all the fibrin associated with the little red corpuscles which give the blood its characteristic colour. If the clot is washed with water, in which the fibrin is insoluble, the coloured globules may be separated, and after treating the solid residue with ether to dissolve fat, we shall obtain pure fibrin as a yellowish-grey substance. The red corpuscles, when examined by the microscope, are seen to be somewhat flattened, and in this respect differ from the oil-globules of cream, which are perfectly spherical (Fig. 1). Pure fibrin does not differ much in appearance from dried albumen or white of egg; in fact, it is, doubtless, the same substance in a different molecular condition, for we know they are mutually convertible one into the other. There is no fibrin in an egg; yet, after incubation, we find it in the muscles of the bird; the albumen therefore must have been transformed into fibrin. The same mysterious process takes place in our own bodies every day. When we partake of cheese or eggs, the casein of the one and

the albumen of the other are converted into the fibrin of which our flesh is built up. The cereal grains derive their value from another modification of fibrin, called *gluten*, which any one can obtain by the simple process described on page 272. In the human body gluten is also converted into muscle; so that we have three flesh-forming principles, similar in chemical constitution, but differing in physical properties.

Thus, albumen coagulates by heat, but fibrin coagulates spontaneously as soon as it is withdrawn

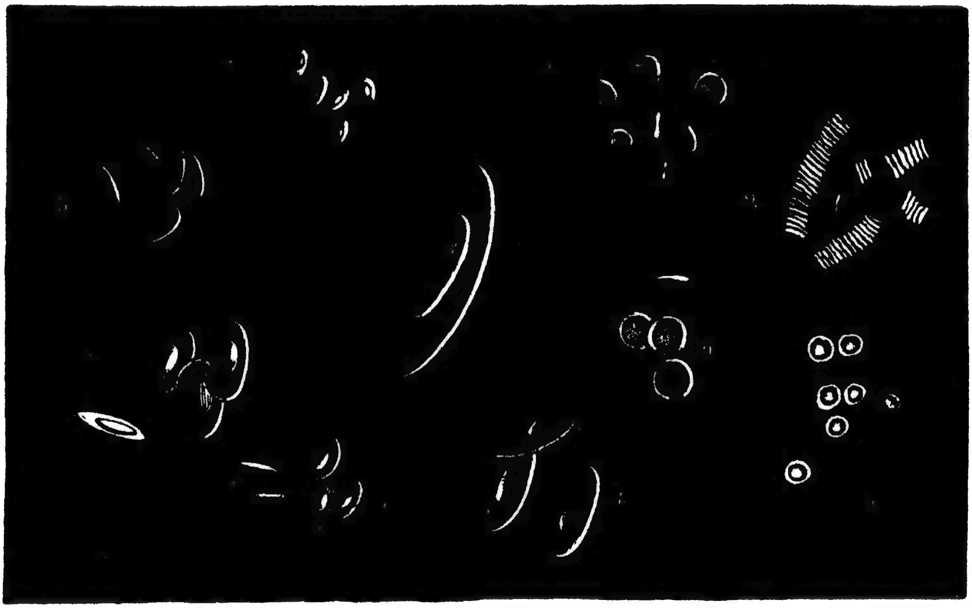


**Fig. 1.—Red Corpuscles of the Blood of various Vertebrate Animals**

(1) Red Corpuscles of Human Blood Imprisoned by the Fibrin in Coagulated Blood; (2) Globules of Human Blood gathered in Rolls; (3) Globules of Human Blood in Bi-concave Circular Discs; (4) Globules of Camel's Blood in Elliptical Discs; (5) Globules of Pigeon's Blood, Elliptic Bi-convex Discs (6) Frog's Blood, Elliptic Discs; (7) Loach's Blood, rounded; (8) Blood of Salamander; (9) Blood of *Lepidosiren*, Bi-concave rounded Discs; (10) Blood of Proteus.

(*a*) Front View of Globules; (*b*) Side View.

from the fluids which keep it in solution. In the blood the fibrin is dissolved by the alkaline salts—that is, the salts of soda and potash—present in the serum; so that, although these salts exist in apparently trifling proportions, if they were withdrawn from the system the fibrin would immediately coagulate, and the blood would cease to flow. This phenomenon actually occurs after death, and in some diseases just before death.

Fortunately, there are few articles of diet, whether animal or vegetable, that do not contain more or less of these valuable salts; and when we come to speak of vegetables we shall notice them more in detail. It has been stated that fibrin is the building material used in the construction of the muscles of all animals.

Now the question arises, What is muscle; and what has it to do with the dinner-table? Well, if you are fond of roast beef, you are fond of the muscles of the ox; or, if you are partial to sole or salmon, you appropriate the muscles of those fish; so that every piece of lean, fibrous flesh brought to table—whether procured from the butcher, poulterer, or fishmonger—is a bundle of muscles. We are all familiar with the muscle of the human arm, and its power of contractility. If we grasp the arm tightly above the elbow, and move the hand towards the head, we shall feel a resistance; because by this movement the muscle, which is attached by tendons at one end to the bones of the wrist, and at the other to the shoulder, becomes shortened, and must therefore increase in diameter. What is here related of the function of one muscle will apply with equal force to all other voluntary muscles. They are the organs by which motion in any part of the body is accomplished. We cannot walk, run, laugh, sing, or perform any kind of manual labour without calling into action various sets of muscles.

There are muscles, such as the heart, which perform work independently of the will. These are called "involuntary" muscles, and they do not present the same fibrous structure as the "voluntary" muscles. If we examine a muscle of the first class, we shall see that it consists of a number of fibres running in a parallel direction from one end to the

other, and joined together by a fine tissue—about which, by and by, there may be something more to say, when the functions of a muscle are considered

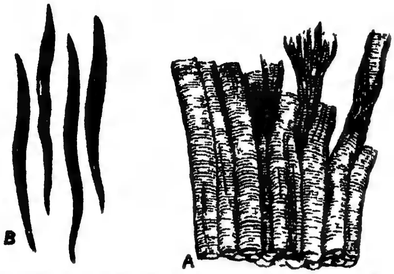



Fig. 2.—Fibres of Voluntary (A) and Involuntary (B) Muscles.

from the scientific rather than the gastronomic point of view (Fig. 2). Amongst the fibres run countless minute blood-vessels, which carry the fibrin for the purpose of building up the solid parts of the structure, and at the same time carry off the effete or worn-out particles which are momentarily being cast off or disintegrated from every muscle, even in a state of rest, but more especially under active exertion. From the blood which circulates through the muscles is eliminated the fat found in their substance and on their surface, as well as certain juices which give to the flesh of animals its characteristic flavour.

The red colour of flesh is due, not to the muscular fibre which composes its framework, but to the blood which circulates through the veins and arteries imbedded in its substance.

If a muscle is well washed, the red colour disappears, and the pale hue natural to the fibrous structure itself is observed. The variation in colour observable in the flesh of different animals is due to the constituents of their blood—as, for example, the proportion of iron—and not to any difference in the chemical composition of the tissue itself. In all animals with a back-bone, fibrin is the building material universally used in the construction of the muscular organs. The flesh of most fish is white from the absence of the red corpuscles in their blood; while that of salmon is yellow from their presence in small quantity. In wild game we find the flesh dark, while that of domesticated birds is much lighter, owing to variation in the chemical properties of the blood produced by change of food. Again, the paleness of veal is produced by the loss of blood which results from the method of slaughtering the calf adopted by butchers in deference to the demand of the public for an article of diet from which the most nutritious element has been withdrawn.

From the flesh of animals used as food we derive three important organic constituents of the human body—fibrin, albumen, and fat—the first two forming muscle and nerve, and the last, by a species of flameless combustion, producing the necessary temperature of 98°, without which the function of respiration would be impeded or altogether cease. The principal agent concerned in the digestion of these compounds is *pepsin*, a powerful solvent stored up in the walls of the stomach, and only poured out when its assistance is demanded. When pure, this fluid is found to be perfectly neutral—that is, it is neither acid nor alkaline; but it appears to be unable to exert any action upon the food without the presence of an acid. Such an acid is found in the gastric juice, which is secreted by the gastric follicles covering the coat of the stomach; and if this acid is neutralised by carbonate of soda, the process of digestion will be arrested.

In some forms of dyspepsia, as heartburn, it is usual to take this alkali in order to neutralise the excess of acid which gives rise to the symptoms complained of; but it is easy to see how this expedient can only be a temporary palliation, and may lead to a serious interference with the digestive function. In these cases it is best to look into their history, and endeavour to find out the cause; and it will often be found that dietetic indiscretion is at the bottom of the evil. A very minute proportion of gastric juice seems to be essential to the complete solution of the food. According to Dumas, water holding a millionth part of hydrochloric acid (the gastric acid) will gelatinise fibrin; and if a few drops of pepsin be then added, the fibrin will be entirely dissolved in two hours at a temperature of 98°.

The artificial pepsin of the chemists' shops consists of the scrapings of mucus from the stomachs of animals, mixed with starch, and—so runs the legend—is of use to those with whom digestion is a difficulty.

But here comes the *pièce de resistance*, in the shape of a round of beef, which we selected for the following reasons:—In the first place, it is one of the best joints, in respect to firmness of fibre and richness of its juices; secondly, it is economical, where you have to provide for many mouths, as the proportion of fat and bone to lean is small; and, thirdly, it looks well on the table. Beef is universally acknowledged to be the most useful and satisfying, if not the most nutritious species of flesh used as food by man. It may be said to be more nutritious than mutton in the sense that its texture is closer, and that, therefore, there is a larger proportion of

fibrin and juices in the same bulk. The blood abounds more in the red corpuscles than that of mutton, and is consequently, richer in iron. There are some other liquid principles, such as *osmazone*, which exist in beef in a more concentrated form, and tend to give it that fulness of flavour so characteristic of it. Beef is pre-eminently the meat for the robust, and those who have to work hard either with their hands or their heads; while mutton, from its greater delicacy and easier digestibility, is better suited to persons of feeble health and sedentary habits. Mutton also possesses the disadvantage of containing more fat than beef.

It must be borne in mind that fat occurs in animals under two conditions. There is the separated fat laid up in masses in what is termed the *adipose* tissue—the fat plain to the eye—and there is the liquid fat or oil, which is associated with the juices of the muscles, and can be expressed in more or less quantity from the leanest meat. The separated fat is stored up in largest quantity in the loins, and being firmer and purer than that in other parts of the body, is sold as suet for puddings and culinary purposes generally. Masses of fat also occur on the ribs, and in superficial layers under the skin all over the body. In prize cattle the solid fat forms a considerable part of the carcase, sometimes amounting to a third of the entire weight; so that in estimating the comparative value of the flesh of animals as food, the adipose tissue must be disregarded, and the lean muscle only subjected to analysis.

Accordingly, it appears from M. Mareschal's researches undertaken on this basis, that in the flesh of the pig—pork, to wit—there is more than twice the quantity of concealed fat than in that of the ox, and more than four times as much as that contained in the fowl. It also appears that there is more water and less muscular fibre in veal than in the same bulk of any of the other kinds of flesh examined, so that the paucity of true nutritive matter in veal is evidenced by chemical analysis, as well as by the experience of mankind.

But our much-prized round of beef is getting cold, and our guests are becoming impatient, so we will proceed to cut it up. We make a transverse section of the joint with a sharp knife, and in this operation cut through several muscles, each of which during life had its own proper function, and was concerned in some particular movement of the body. In cutting through the muscles, we necessarily divide the fibres with their investing sheaths, the nerves and the blood-vessels. If the meat is not too much cooked, the sheath of "connective tissue" may be seen in some places separating one bundle of fibres from another. The nerves are fine whitish threads, issuing from the spinal cord, and penetrating every muscle for the purpose of directing its movements. The voluntary muscles are called into play by an effort of the will, and the nerves transmit the command to the muscle to be exerted. The nerves, however, are so minute that they are not of much importance in a gastronomic point of view; but the little blood-vessels, which we are dissecting by millions at a stroke, determine in a great measure the value of the joint. From their ruptured mouths is pouring the rich, dark-coloured gravy so suggestive of the exquisite tenderness which characterises first-class beef. This gravy is composed not only of the blood, but of the albuminous juices contained within the spaces between the muscular fibres, and the fat, or rather oil, secreted from the blood, and stored up in the substance of the muscles, probably for the purpose of facilitating motion. It will be perceived, then, that the liquid constituents of the joint are by no means the least important part of it. The blood contains valuable compounds, containing iron, potash, soda, and lime, without which the preservation of health would be impossible, even with a due supply of albumen and fibrin. The solidity of our bones, for example, depends upon a regular supply of phosphate of lime, the deprivation of which would reduce the solid framework of the body to the condition of mere cartilage. Something approaching to this condition is seen in the disease occurring amongst children, known as *rickets*, which results from the use of food deficient in lime. A pale, bloodless joint should be rejected, as not only unserviceable, but tough and unpalatable. To purchase low-priced meat is really very poor economy; although a working man's wife, with only a few shillings in her pocket, cannot be expected to take home a round of beef or a sirloin. She is often obliged to content herself with a piece of the brisket or spaud, or some part better fitted for boiling than roasting. A piece of the shin, boiled with the bone, and flavoured with onion and herbs, will make a very nutritious and agreeable soup, especially if thickened with peas or rice. Cookery is an art of which the poor in this country are profoundly ignorant. Having secured the fattest and most unprofitable pieces of meat, they cook them in such a way as to produce the most extravagant waste of nutritive material. The great aim of the cook should be to utilise all the valuable parts of the viand under treatment, and to prevent the

escape, as far as possible, of the contained blood and juices. With this object in view, the meat to be cooked, whether by boiling or roasting, should be immediately exposed to a degree of heat sufficiently great to coagulate the albumen externally, and thus form an impenetrable coating, which will imprison the liquid constituents throughout the process. To do this effectually, a heat of at least 170° must be at once applied, and, after a few minutes, may be reduced. The very reverse of this method is often adopted. The meat is placed before a slow fire at first, and the heat gradually increased. During the operation the juices are constantly running out with the dripping, and the greasy mixture, being carefully ladled out of the tin, is served up as gravy to accompany a joint as dry, if not as tough, as a piece of South American junk. If it is a boiled joint, the case is still worse; for the water holding in solution the albuminous matters which have exuded is thrown away, and there is not so much as a symptom of gravy to assist the unfortunate members of the family in getting down the shapeless mass of rags which does duty for "the joint." If the meat were put at first into water near the boiling-point, a casing of coagulated albumen would be formed, and the juices preserved within till the carver's knife set them free. In making soups, or "beef tea," when our object is to extract every vestige of soluble matter, the reverse process must be adopted. The meat, cut up into very small fragments, is put into cold or tepid water, and the temperature gradually raised, care being taken to keep it under the boiling-point. In this way we shall obtain a concentrated solution of great sustaining power, and invaluable to invalids who cannot take solid food.

In estimating the percentage of nutrient matter in meat, it is important to bear in mind that a pound of raw meat will weigh considerably less when cooked. Owing to loss of fat, water, and other liquids, 16 ounces of beef-steak when cooked become reduced to 12 ounces. In mutton, the loss is somewhat greater, from the larger proportion of fat and water. An approximate calculation only can be made of the relative proportions of fat and nitrogenous or flesh-forming material, in the flesh of animals as a class, for the proportions differ considerably in different individuals, according to the breed and the extent to which the fattening process has been carried on. Thus, a prize ox may have 34 per cent. of fat, and only 15 per cent. of nitrogenous matter; while a lean one may afford 16 per cent. of fat and 18 of flesh-forming elements. In pigs the fat is still more abundant: in some cases the feeding has been conducted with such skill and success that the poor animals rejoice in, or perhaps deplore, the existence of 50 per cent. of fat in their composition. In average specimens, there is about 14 per cent. of nitrogenous matter, and 28 per cent. of fat.

This brings us to the subject of pork, of which we warn our readers to eat very sparingly, for the following reasons:—

In the first place, it is indigestible; secondly, it is too oleaginous, and communicates an unpleasant greasiness to the skin; and thirdly, it is liable to disease. There is, no doubt, a peculiar richness of flavour in roast pork which makes it popular, and sucking-pig is not surpassed in delicacy by the flesh of any animal. When we consider how extensively salted pork in the form of bacon is used by the English poor in the place of fresh meat, and what an important part the pig plays in Irish domestic economy, swine's-flesh becomes invested with an importance which the rich are not accustomed to attach to it. Bacon is prepared by rubbing the fresh meat at frequent intervals with a mixture of salt and saltpetre, till every part is impregnated. The process occupies about three weeks, after which it is removed from the pickle and dried. The famous Wiltshire smoked bacon is subjected to the action of wood-smoke after the salting process, by which it absorbs traces of the kreasote, which gives the smoke its peculiar pungency.

The effect of the treatment to which bacon has been subjected is to abstract a large quantity of the nutritive juices of the pork, as well as more than half the water; so that in dried bacon there is not more than 15 per cent. of the latter, while the nitrogenous, or really nutritive element, is reduced to 9 per cent., the bulk of the remainder, or 74 per cent., consisting of fat; these figures thus conveying a tolerably correct notion of the value to be placed on bacon as an article of diet. A few words only need be devoted to veal and lamb. The flesh of young animals generally is deficient in the elements of strength, and therefore unfitted for food. Veal is especially indigestible, and is rendered still more unwholesome by the melted butter with which it is often served. A veal cutlet soused in the conventional melted butter and flour may be a luxurious dish, but it is strongly suggestive of dyspepsia; while those who rather like the nightmare may be recommended to indulge in the same delicacy late in the evening. The bones of the calf, however, abound in gelatine, and are admirably fitted for the preparation of soups.

Much discussion has arisen respecting the merits of gelatine from a dietetic point of view, the probability being that, as it is absent from the blood, it possesses no nutritive qualities whatever, and that the virtues of "calf-foot jelly" are accordingly somewhat mythical.

Fish and game we may dismiss thus briefly. Both are deficient in nutritive power, and can only be regarded as agreeable adjuncts to our ordinary meat diet. Fish having red blood, such as the salmon, approach nearer in the character of their flesh to the suck-giving animals than white fish, especially as their muscles usually contain fat; while white fish, with the exception of the eel and some others, have the fat chiefly stored up in the liver, as in the cod. Fish contain three times as much phosphorus in their composition as quadrupeds. As phosphorus is an essential constituent of the human brain, and requires renewal in proportion to the work which that organ is called upon to perform, it follows that a diet partly composed of fish will be serviceable to teachers, students, authors, and others whose mental labours are severe, as well as to those suffering from mental distress and anxiety.

In game, too, the red corpuscles of the blood exist in small proportions, the ratio compared with beef and mutton being about 1 to 12.

Of course, our dinner-table is well provided with vegetables, which are of considerable importance, notwithstanding that they contain from 80 to 90 per cent. of water. Most of our culinary esculents were unknown here before the time of Elizabeth; and the diminution in cases of scurvy since that period has, not without much show of reason, been attributed to their introduction into our *cuisine*. They are rich in potash, which is an antidote to many skin-diseases, and is required, as we have already remarked, to prevent the coagulation of fibrin in the blood. Cabbages and other plants of the order *Cruciferæ* contain sulphur, which is also remedial in certain skin-affections.

We must now speak of some formidable diseases, which result either from the excessive use of meat in itself wholesome, or from the use of flesh derived from diseased animals. As a general statement, it may be asserted that we eat too much meat. All the constituents of the human body can be derived from vegetables; and without ranging ourselves on the side of vegetarianism, we believe that much less harm is done by the excessive use of vegetable diet than by a corresponding excess of animal food. The latter produces gout and gravel, and aggravates the tendency to rheumatism; while rheumatic and other fevers are encouraged by the setting up of putrescence or fermentation in the blood. Still the nutritive elements in vegetables are not sufficiently concentrated to render it advisable to restrict ourselves altogether to their use. As a general rule, six ounces of cooked meat per diem is an ample allowance, especially for those who take milk, eggs, and cheese in addition. A word of warning is due to those who like their meat underdone. Pork is sometimes sold in a state unfit for food, as the pig is liable to the "measles." This is by no means such a trifling disorder as the infantine malady of the same name. It is produced by a creature—or stage of one—called the measle, or bladder-worm (Fig. 3). It penetrates the muscles of the animal in large numbers, and when comfortably settled down incloses itself in a little capsule, or bladder (cyst). Here it remains till some one devours the pork, and gives the little parasite a fresh start in life. It is not long in taking advantage of the scope afforded it, and in a few months develops into a tapeworm with 1,200 joints, and a head armed with suckers, to enable it to adhere to the intestine. The bladder-worm, then, is simply an intermediate stage in the life of the tapeworm (Fig. 4): and as the digestive process does not affect it, except so far as to promote its development, it must be sedulously avoided.


Fig. 3.—Measle-worm (*Magnified.*) (a) Mouth.

The question is, What precautions are we to take, if we are to eat pork at all? There is one thing that these horrible creatures cannot stand, and that is a temperature of 160°. Well, then, the remedy is clear:—Have the pork well cooked through — not superficially only—and there will be an end to the career of the measle-worm. The common tapeworm, Fig. 5 (*Tænia solium*), is more often derived from the minute bladder-worm found in beef, so that it is important that we should avoid the common practice of eating this meat in a semi-raw state.


Fig 4.—Head of Tape-worm. (*Magnified.*) Showing the Four Suckers, and Ring of Hooks (a).

Another parasite, still more to be dreaded, remains to be described. It is the *Trichina* (Fig. 6), a little creature only the twenty-fifth part of an inch in length, but armed with terrible boring instruments, which enable it to pierce the firmest muscles, not excepting the heart itself. It propagates by millions, and, passing through the walls of the intestines, sets out on

its migrations. It stops at nothing except bone; and insinuating itself into the substance of the

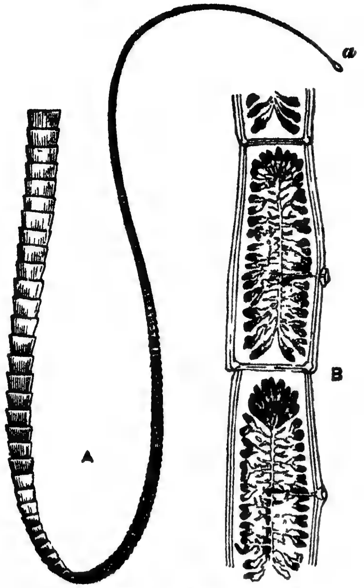



**Fig 5.—Head and Neck of Tape-Worm**
A, Head (a) and Body, showing gradual Increase in Diameter, B, segments or Joints enlarged, each containing 30,000 Ova

muscles, spreads throughout the entire body. Some idea of their numbers may be gathered from the fact that the body of an unfortunate German, who died a few years ago, was estimated to contain

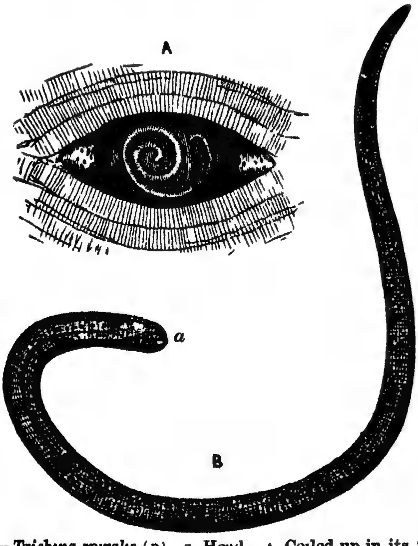



**Fig. 6.—*Trichina spiralis* (B), a, Head. A Coiled up in its Spindle-shaped Capsule or Cyst.**

fifty millions. The Germans and Danes, from their habit of eating raw sausages and ham, are particularly liable to be trichinised; and, notwithstanding the vigilance of the sanitary authorities in examining microscopically the hams sold, many still die or suffer severely from *trichinosis*.

Some of our younger guests, who may have a *penchant* for pastry, may feel some disappointment at the non-appearance on our table of their favourite pies and tarts; but having put a veto upon veal and pork, it would be inconsistent in us to serve up an article of diet equally objectionable. The action of the baking process upon the butter and lard used to lighten the paste is to render the oleaginous matter difficult of solution by the bile and pancreatic juice: the result is the production of liver derangement and consequent biliary disorders, accompanied by a dark and unhealthy looking skin and acid eructations. Still, we may find the balm of consolation in a host of boiled puddings, which are not open to the same objections as baked preparations. Here is a maccaroni pudding, which, in a nutritive sense, may well be placed at the head of the list. Maccaroni is nearly pure gluten or vegetable fibrin, and contains as much nitrogenous or flesh-forming material as meat or cheese. Small pieces are simply boiled in milk, with or without eggs, and eaten either hot or cold. The gluten, however, soon decomposes. Puddings made of Indian corn-flour come next in value; but care should be taken that a spurious article composed of ground rice is not purchased for the genuine corn-flour. It is much whiter than that made from Indian corn, and is almost valueless. Rice puddings are useful from the milk and eggs they contain; but the excess of starch in rice renders that grain less nutritious than other cereals. Fruit puddings may be used with advantage, especially in summer and autumn, at which season ripe fruit, from the acids and salts it contains, is so valuable as a blood purifier.

But the arrival of the cheese reminds us that our frugal dinner is nearly finished, and that we can only very briefly refer to the subject of *casein.* This is the form in which nitrogenous matter is supplied to the young of the mammalia, as it is the only flesh-forming element in milk, in which it is kept in solution by the presence of an alkali. If this alkali is neutralised by an acid, the casein separates as curds. The curds salted and pressed in a mould constitute cheese. The source of the acid used in this country is rennet, or the stomach of the calf; but on the Continent muriatic or hydrochloric acid is used. Cheese contains nearly 40 per cent. of casein, or twice the quantity of nutritive

matter found in cooked meat. Its value to those who can digest it is, therefore, very great; but, unfortunately, few but those engaged in outdoor labour can appropriate it. The richness of a cheese depends upon the butter it contains. In making Stilton and Double Gloucester cheeses, the cream from one day's milking is added to the milking of the next day, so that an additional quantity of butter is incorporated with the curds, and imparts that richness of character which is so much prized. In some counties, as in Suffolk, the milk is first skimmed, and afterwards made into cheese. This cheese is so hard that the proverbial digestion of an ostrich is required for its assimilation. Cheese is often coloured red by annotto; and the green mould, so much relished by some people, is imitated by powdered sage-leaves. The famous Gruyère cheese is made by the addition of goats' milk to that of the cow. The cavities in it are caused by gases generated during semi-putrefaction. Cream cheeses are made of the impressed curds, which contain some portion of whey, so that they soon undergo decomposition and become fluid. Casein occurs in peas, beans, and other plants having butterfly-shaped flowers, and belonging to the family *Leguminosæ*.

Having eaten our cheese, our meal is over. Our talk has been necessarily short; but we may, at least, have shown the importance of providing for the wants of the inner man upon some intelligent principle, and not simply in response to those blind impulses which it is one of the objects of education to subdue.

# WHAT IS AN ANIMAL?

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THE title of this paper may sound somewhat paradoxical in the ears of not a few readers; and this for the simple reason, that the ordinary and commonplace distinctions between animals and plants are, in their opinion, both obvious and sound. Is there any likelihood, it may be asked, of our confusing a bird with the tree on whose kindly branches it perches? Are we likely to mistake the ox for the grass it crops? Or is there any relationship whatever, between the flower and the fair being whose person it may serve to adorn, and whose beauty it may enhance? True, the bird and tree, ox and grass, flower and wearer, are living beings. All possess life; and with this admission the likeness and relationship may be thought to end. There is no task, indeed, for the performance of which the popular mind may regard itself as being better fitted, than that of separating animals from plants. And any suggestion to the contrary, and which would hint that possibly we might experience some difficulty in framing an exact definition of one group or the other, would be naturally met with incredulity, and even scorn. Animals move, whilst plants are fixed; animals possess no leaves or flowers, whilst plants have both; animals have nerves and feel, plants exhibit no sensations. The form, the possession or absence of powers of motion, and the common attributes of the life of each group of living beings, thus serve apparently, and in the most satisfactory manner, to map out with bold outlines the limits of the plant creation, as distinguished from those of the animal world.

Such is the philosophy of every-day life. Scientific philosophy, however, is forced to take a wider view of matters than can be obtained from the popular standpoint; and one result of a more comprehensive glance at the fields of living nature is to throw very considerable doubt on the validity and worth of the common modes of separating animals and plants. The popular ideas deal with the higher forms of animals and plants, and concern themselves with the separation of what may be seen with the unassisted sight, and with characters in animals and plants that can be discerned without any exercise of skill. But beyond the visible world lies a universe of life, invisible save to the eye of the microscopist. Other worlds than ours rise at his beck and call—worlds peopled with beings so diminutive that their dimensions are estimated by standards compared with which a hair's breadth is to be esteemed gigantic. In these regions of the infinitely small there are included beings the exact nature of which, as we shall presently see, it may be hard or even impossible to discover. But even within the visible portion of living nature

which exists around us, there may be much on which the far-seeing glance of science rests that is dubious and uncertain. It may be shown that in many cases the common distinctions between animals and plants are utterly valueless when applied to the identification of some tolerably well-known forms of life. The whole question before us is one which has grown out of the increasing research of modern times; the advances of science thus resulting in the demonstration of our ignorance of many of the fields of inquiry which lie before our gaze. And in what follows we shall endeavour to show, not merely that the task of separating some animals from some plants is attended with great difficulty, but also that it may be impossible to declare, in the present state of our knowledge, what are the essential characters of the animal, and what the unmistakable features of the plant.

A simple experiment in the production and development of some lower forms of life, will serve as a starting-point for our inquiries into the special characteristics of the two great groups of living beings. Some chopped hay is placed in a vessel, and through the addition of water an infusion thereof is made. This infusion is further allowed to stand freely exposed to the air for a week or so, and at the expiry of that period we place a drop of the liquid under a microscope of high power. Then a wonderful sight bursts upon our view. The fluid which the ordinary observer might have expected to be simply turbid from the presence of particles derived from the dead hay, is seen literally to swarm with life. Rushing hither and thither across the field of the microscope are numberless specks, which our first glance assures us are living beings. When the eye has had time to become better acquainted with the scene on which it rests, it may assort or parcel out the organisms of the infusion into various kinds or grades. There, for instance, are minute rod-shaped bodies which wriggle about with an ill-defined, jerking motion. These are *bacteria* (Fig. 1). There, again, are bodies of different form and of larger size, which appear to consist of a number of the rod-like bacteria united, end to end, and which the biologist names *vibrios* (Fig. 2). But we also discern bodies which are different from either of the organisms just mentioned, and


Fig. 1.—*Bacterium termo.* Magnified 600 times (*a*), and 1,600 times (*b*).

Fig. 2.—*Vibrio.* Magnified 800 times.

Fig. 3.—*Monas lens.* Magnified 1,000 times.

which attract attention from the rapidity of their movements, as they flit hither and thither like swift vessels, through their miniature sea. Stay; there is one of these active bodies (Fig. 3) which has come to rest for awhile, and which permits us, luckily, to obtain a better view of its form and nature. You notice it to be pear-shaped, and if you are capable of forming an idea of the size of the minute objects with which the microscopist deals, you will not be surprised to learn that the body you see before you measures about the three-thousandth ($\frac{1}{3000}$th) part of an inch in length. This pear-shaped speck bears at its narrow end a long tail, formed of a filament which we may compare to a miniature eyelash, and which has been named a *cilium*. By more careful observation we might see that a second tail, or cilium, was present, and that this latter appendage was also attached to the slender extremity of the body. The body itself presents few or no features for remark. But if we are fortunate in our selection and manipulation of our specimen, we shall be able to see within the body a clear round space, which ever and anon contracts itself with a jerk and disappears, only, however, to reappear with its clear surface as before. Now the creature is off again on its peregrinations, to add one more unit to the hustling and jostling crowds which people the drop of water before us. You are able, as it moves, to see that the longer of the two tails, or ciliæ, serves as a kind of propeller, whilst the second tail extends behind; and you may sometimes observe the creature to anchor itself by the second cilium, and then spin round and round the fixed point like some curious top of vital construction. Then it releases itself, and is off again on its wild career—jostling its friends and neighbours in the struggle for existence in which animalcule and man appear alike to participate.

Such is a brief description of a sight well known to every student of the microscope, but which, despite its familiar nature, can rarely fail to evoke interest and to serve as the exciting cause of a laudable and scientific curiosity. What is this creature which is seen to be represented by its thousands in a drop of hay-infusion? The popular idea that power of motion is the exclusive right of the animal would unhesitatingly declare that the creature falls under the paternal care of the zoologist. But the man of science would reply that whilst the *Monads*, as he terms these creatures, *may* be animals, he sees no adequate reason, on the other hand, for refusing assent to the statement that they *may* be plants. Let us try to examine the question somewhat in detail, and place ourselves in the position of a

counsel whose aim it is to convince a jury (of readers) of the impossibility of drawing definite distinctions between the animal and plant worlds, or of saying absolutely, regarding any organism "That is an animal," or "This is a plant."

The opposing side begin the trial of the cause by asserting that animals move, whilst plants are fixed, and that because our monad moves, it must therefore be regarded as an animal. Very good. Let us accept this first point for what it is worth, and judge it on its own merits. Our opponents, it is clear, are keeping the higher plants and higher animals exclusively in view. But they must remember that our aim is not merely that of separating the higher animals from the higher plants, but of constructing an *absolute* definition and idea of an animal and of a plant. If our definitions are to be of any service whatever, they must include in their scope *all* animals and *all* plants. And as our opponents will readily admit this reasonable demand, we proceed to adduce evidence against their first proposition—namely, that motion is an unfailing characteristic of the animal. Firstly, let us consider whether all animals move, and whether all plants are fixed. What shall you say of the coral-polypes (Fig. 4), which are not merely rooted, but which in their strong investments appear to possess solidity, in addition to fixation of body? What can be said of the sponges, now proved to be true animals; or of the "zoophytes," which grow rooted and attached from the oyster-shells and stones brought up from the depths by the oyster-dredger? And in addition to these examples of rooted animals, might be mentioned the "sea-squirts" (Fig. 5) or *Ascidians*—related somewhat to our shell-fish—the sea-anemones (Fig. 8), the *Polyzoa* or "sea-mats" (Fig. 7), and many other truly animal forms of by no means the lowest grade. But even if it be said that the sponges, corals, sea-anemones, and sea-squirts, are free and active in the young and juvenile stage of their existence, this point may be fully met on our side by the mention of the curious fact that not only do many lower plants swim freely about in their young state, but some are actually free-swimming throughout their entire existence. A sea-weed begins life as a little free-swimming speck, propelled through the sea by cilia, similar in nature to those Other lower forms of

Fig. 5.—*Ascidia pedunculata*, one of the Tunicates or "Sea-Squirts.

Fig. 4.—*Dendrophyllia ramea*, one of the "tree-corals," showing the little cups in which the polypes lived. (*Half natural Size.*)

plant life, exemplified by many microscopic plants that attach themselves to water-weeds, and which are composed exclusively of cells, may be seen to liberate the living matter of these cells in the form of little free-swimming particles. Each particle is termed a *zoospore* by the botanist,

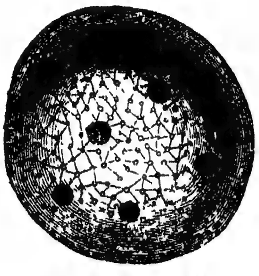

Fig. 6.—*Volvox globator.* (Magnified 700 times.)

and were you to see it swimming side by side with your monad, you would experience extreme difficulty in distinguishing between the two organisms —if, indeed, you could separate them at all. And if bodies indistinguishable from the monads are thus seen to arise from true and undoubted plants, why may not the monad be a plant? Moreover, there is one notable plant which does not appear to be fixed at any period of its existence. Such is the *Volvox globator* or "Globe Animalcule" (Fig. 6), as it was formerly named, under the idea that it belonged to the animal creation. To see this organism rolling over and over upon itself, in company with the animalcules you have obtained along with it from a stagnant pool, is a sight which goes a very great way in convincing one of the futility of advancing power of motion as a means of distinguishing between animal and plant life (p. 353). Notwithstanding its mobile life, the Volvox is a true plant, made up of an aggregation of little monads, each of which, like the monad we first saw, has a pulsating space, and two cilia for locomotion, but, in addition, containing *chlorophyll*, or the green colouring-matter found in plants (p. 295). And it is a noteworthy fact, that the old division of the Infusorian animalcules, as defined by Ehrenberg, has long since been resolved into a multitude of separate and distinct organisms. Many of the so-called "animalcules" of this observer are now known to be merely the locomotive and young stages of lower plants, and some of the "animalcules" of tolerably recent years—such as Volvox itself—have been ascertained to be true plants of adult kind.

Thus, it may be held as proved, we think, that power of motion *per se*, is a characteristic of little or no value in drawing lines of demarcation between the animal and the plant. We may pronounce the same verdict on the distinctions which are commonly drawn from *form*, and from the general shape and configuration of body. Unquestionably, were the higher animals and plants the sole subjects of remark, this latter method of separating them would be found efficacious and trustworthy. But recollecting that we must include all animals and all plants in our definition, we see that amongst the lower forms of life there exist many organisms which, as far as mere form and appearance are concerned, might belong either to one or other group. Our monad is exceedingly like many Infusorian animalcules, but it just as closely resembles many lower forms of plant life. Nor is this confusing identity of form with plants, peculiar to lower animals alone. Here (Fig. 7) is an organism we have just picked up on the sea-beach. It appears to be a piece of pale brown sea-weed, and as a sea-weed, it is almost invariably preserved in herbaria by seaside visitors, who most laudably unite a study of nature with the labour of holiday-making. In dredging-expeditions

Fig. 7.—*Flustra foliacea*, one of the "Sea-Mats."

you obtain specimens of the same organism growing rooted to oyster-shells, and to stones, and as you behold it thus attached, you might have little doubt left that you had fished up a marine plant from the sea-depths. But scan the surface of this *Flustra* or "Sea-mat," as it is called, with a pocket-lens, and

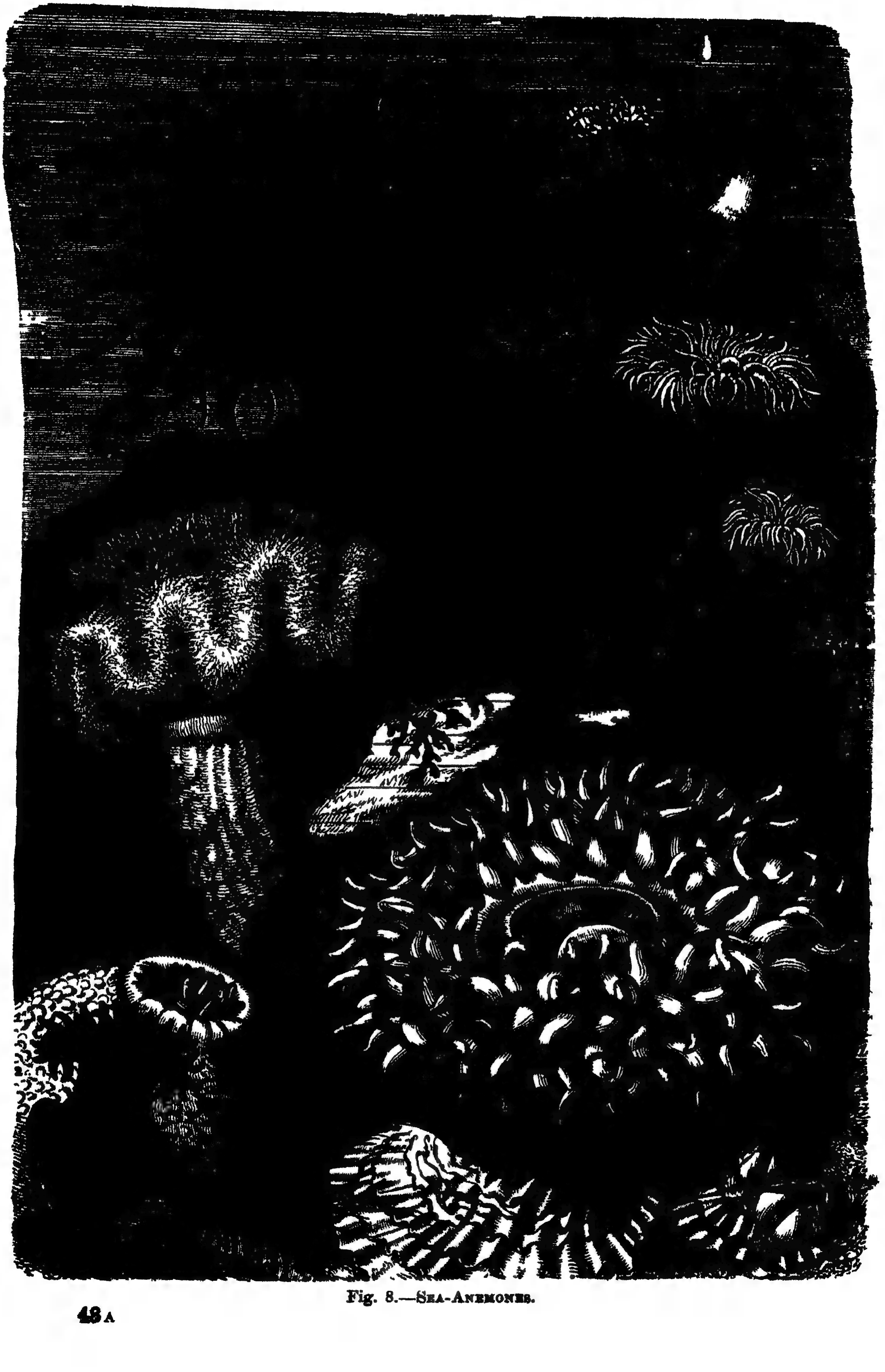

Fig. 8.—Sea-Anemones.

you will see that it presents a very regular division into cells, which crowd both surfaces of the organism. Or, better still, examine a bit of living Flustra, microscopically, and then all your ideas of its plant-nature will be ruthlessly dispelled. For you then see that from each cell of this supposed sea-weed comes forth a little crown of tentacles, forming the "head" of a little animal, which, were your anatomical skill more advanced, you might demonstrate as possessing a mouth, stomach, intestine, and other belongings of the animal world. The Flustra, in short, is a colony of animals, numbering its population by hundreds, but which, nevertheless, grows by budding, and in the strange verisimilitude of a plant! Nor is the Flustra singular in its mimicry of the vegetable world. On the sea-shore you may pick up dozens of specimens of equally curious animal organisms, collectively known as "zoophytes," and which mimic in the most exact fashion the forms of trees and shrubs. The well-known *Sertularians* or sea firs (Fig. 9) get their popular name from their resemblance to fir-trees; other species mimic shrubs and vegetation of more irregular shape, and with spreading branches, deceive the seaside visitor into thinking they are the waste of marine forests. Each zoophyte, again, is simply a colony of animals, of lower rank than the tenants of the Flustra-colony, but, like the latter, growing in the exact likeness and fashion of plants. Thus, the assertion that the *form* of the animal is always characteristic must fail equally with the statement regarding the value of the power of motion in distinguishing the animal from the plant.

But, it might be asked if chemistry, with its fertility of resource, with delicacy of experiment, and with almost endless analytical powers, is unable to select any substances, the possession of which would form an unfailing characteristic of either group of living beings? To this question a negative answer must be given. Cuvier, the celebrated French naturalist, affirmed that the element nitrogen was peculiar to animals; but this statement has, years ago, been proved to be utterly erroneous, and all other attempts at the purely chemical separation of animals and plants have likewise failed as our knowledge of organic chemistry has progressed. The living substance of animal and plant bodies is seen to be essentially identical. It consists of the matter now well known under the name *protoplasm;* and the farther back we trace the life-history of animals and plants, the more confusing in their chemical composition do they become. So that the living substance found within the cells of plants, and of which the bodies of the lowest animals are formed, and that of which the germs of high and low animals alike are composed, is seen to be identical under the strictest examination of the modern chemist. Thus, whatever differences in form, in chemical composition, or in other points, are afterwards evolved,

Fig 9.—The Silver Sertularia, one of the Zoophytes known popularly as "Sea Firs."

there exists a perfect identity in the young condition of animals and plants, in respect of the composition of the living matter from which they are formed.

It might also be shown that some substances long regarded as belonging exclusively to plants are now known to be manufactured as natural products by animals. The *chlorophyll,* or green colouring-matter of plants, occurs in many animalcules—this fact rendering the identity of many of the lower forms

of life more and more confusing—as well as in animals of higher grade. And a starchy substance known as *cellulose* (p. 52), of which the walls of plant-cells are composed, is found abundantly in the outer layer or covering of the bodies of those Molluscoid animals named "Sea-squirts" or Ascidians (Fig. 5). Sugar and starch, known to every one as vegetable products of characteristic kind, are now ascertained to be manufactured in a perfectly regular fashion by animals, which, as it would seem, are bent on the close imitation of the chemistry of plants. And stranger still, it would appear that the chemical and vital processes of animals are imitated by plants; for it has been shown that in the developing seed of a vetch there exists a principle, or "ferment," as it is called, allied to the "sweet-bread" juice or pancreatic secretion of animals. By means of this secretion, the young plant as it springs from the seed is able actually to "digest" the starchy and nitrogenous matters within its reach. The digestion of flies by the "Venus' fly-trap" (*Dionæa*) and by the Sundew (*Drosera*), as described in another paper (p. 240), also illustrate the imitation of the animal processes by plants.

And just as the chemist increases our difficulties by showing us the similarity in substance of animal and plant bodies, so also does the microscopist fail us when we apply to him for aid in separating the two groups of living organisms. If animals and plants are to be regarded as alike in composition, they are no less similar in essential structure. Place the tissues of animals under the microscope, and they are seen to be composed of the minute bodies to which the name of "cells" is given. Examine plant-tissues, and "cells" again appear as the units of which the plant as a whole is built up. And once again, if the lower animals and plants be microscopically compared, their substance, which defies separation by the art of chemistry, equally defies divorce at the hands of the microscopist. The protoplasm of lower animal and plant bodies is literally indistinguishable. If the germ of the higher plant, and that from which the higher animal springs, be examined by the microscope, the differences which become so apparent in after-life are seen to disappear in a primary resemblance, so close in all points, that the task of separation appears simply hopeless.

It may now be said that, granting the futility of the foregoing methods of scientific examination in enabling us to say wherein lie the essential features of the animal and the plant, the presence of nerves, and the power of receiving and of acting upon sensations, might be regarded as a characteristic of the animal as distinguished from the non-sensitive plant. But in a previous paper (p. 179) it has been shown that the Venus' fly-trap, the sensitive plant, and other plants, are highly sensitive; and we then advanced reasons in our opinion of greater force than any that may be given to the contrary, in support of the proposition that sensation was universally diffused through living nature. Wherever the primitive life-substance of protoplasm exists, it may be held that there sensation is present—lowly-developed it may be, but still undoubtedly manifested, as we may see when we regard the movements in the cells of lower plants, or the better-defined acts of animalcules. The arguments for the universal recognition of sensation as an invariable concomitant of life itself are both reasonable and well founded on analogy.

The assertion that animals may be invariably known by the possession of a mouth and stomach is disproved by the consideration that many parasitic animals—for example, the tape-worms, the male "wheel-animalcules" or *Rotifera*, and many animalcules—are destitute of, it may be, the veriest rudiments of a digestive apparatus. The animal commissariat in such cases is conducted essentially on the principles of the plant; such animals in most cases living by the absorption of fluid matters in the absence of an alimentary system. It may be admitted that it is a characteristic of most animals that they can feed on solid matters, and as a rule on *living matter* only; whilst their plant-neighbours are compelled to subsist on "slops"—that is, liquid and gaseous food, or *inorganic matter* derived from the soil and atmosphere; the liquids, however, containing solid matters in solution. But there are some lower plants allied to the *Fungi* which present us with exceptions to these latter rules. Many parasitic plants feed on the juices of other plants—that is, on living matter. And what shall we say of *Æthalium*, the so-called "flowers of tan," a fungus growing in tan-pits, which not merely begins to exhibit independent movements at certain periods of its existence, but at these periods appears to subsist on solid food, like a veritable animal? Thus even a single example—and *Æthalium* is not alone in respect of its singular habits—may vitiate a distinction which, as applied to the generality of plants, is of sufficiently stable kind. Connected with the subject and question of the *food* of the two groups of living beings, is that of the gases necessary for

the maintenance of animal and plant life respectively. Every one acquainted with the merest rudiments of human physiology knows that animals require a due supply of *oxygen* for the maintenance of their vital functions (p. 218); and that plants, on the other hand, demand *carbonic acid* as their gaseous food. Could this rule be "made absolute," as the lawyers have it, the test of the exact nature of a living being might be referred to the capability of the former to inhale oxygen and to emit carbonic acid, as a part result of its bodily waste. The plant, on this showing, might conversely be known by its power of reversing this operation, and by its inhaling carbonic acid and giving out oxygen as the result of its vital chemistry.

But is it true that all plants absorb carbonic-acid gas, and exhale oxygen? Let us refer the matter to the chemist and botanist as arbitrators, and let them detail the results of their experience. As you walk in a garden on a bright summer's day, your eye is pleased with the grateful green of the vegetation around. The botanist tells you that this green colour—of all hues the most grateful and refreshing to the human eye—is to be taken as a test of a plant's capacity to subsist on carbonic acid. Wherever you see a green leaf—no matter whether it forms part of a stately tree, or exists in a lowly blade of grass—the botanist will inform you that there the great operation of plant-life may proceed; and that within the leaf-tissues, carbonic-acid gas, through the exercise of the vital chemistry of the plant, is being split up or decomposed into its constituents—carbon and oxygen. The carbon, he will further tell you, is retained by the plant to serve for food, whilst the oxygen is liberated, and passes back to the atmosphere to afford food for the animal. But our botanical friend would also inform us that before the green colouring-matter can thus decompose the carbonic acid, it must be subjected to the action of light. Light forms, in fact, the second condition required for the performance of this chemical act on the part of the plant; the presence of chlorophyll being the first condition. What, then, will happen when the daylight fades, and darkness falls on the plant world? His reply is that in the dark the green plant becomes an animal, and, like its living neighbour, breathes oxygen and emits carbonic acid. Hence this distinction of inhaling carbonic acid and exhaling oxygen on the part of the plant is only a functional one, and at best one of temporary nature. Depending on it alone, we should be compelled to call a buttercup or any other green vegetable, a plant in the light, and an animal in the dark. Further, it is a distinction which does not hold good for the whole vegetable kingdom, and in this latter phase it must also be regarded as unsatisfactory. All plants are not green, and such as want the green hue are therefore found to be incapable of utilising carbonic acid. A mushroom, a toadstool, and others of their fungoid neighbours, have, in consequence of their lack of green colouring-matter, no partiality for carbonic acid. Habitually and normally, they are therefore animals in all essential particulars relating to their breathing; since they inhale oxygen and emit carbonic acid at all times, and whether in the darkness or in the light.

It is time, however, to call a halt to this process of scientific fault-finding, and to the task of showing how completely worthless most of the distinctions which the naturalists of bygone days drew between animals and plants, have been rendered by the progress of scientific research. Are all distinctions, then, of no avail in this task of separating one group from the other, and are we literally unable to say at the present time of some organisms, "This is an animal, and that is a plant"? To these questions an affirmative answer must be returned. There are some lower forms of life—and the Monads are of them—which may either be one or the other. So hopeless have some biologists become of drawing distinctions between animals and plants, that they have proposed to construct what has well been termed "a kind of biological No Man's Land"—a territory belonging neither to the animal world nor to the plant world, but composed of uncertain living units, which are at home in neither kingdom. Such is the "Regnum Protisticum" of some writers. By most biologists, however, this arrangement has not been received with favour, for the construction and admission of this neutral territory or "refuge for the destitute," seems to amount to a tacit avowal of our absolute incapacity to separate out its members into their proper grades in the two kingdoms of living nature.

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